ALBERT R. MANN
LIBRARY

NEW YORK STATE COLLEGES
OF
AGRICULTURE AND HOME ECONOMICS

AT

CORNELL UNIVERSITY

Cornell University Library
S 517.N45C75 1961

Agriculture

3 1924 001 149 966

mann

Cornell University Library

The original of this book is in
the Cornell University Library.

There are no known copyright restrictions in
the United States on the use of the text.

http://www.archive.org/details/cu31924001149966

AGRICULTURE

AGRICULTURE

R. P. CONNELL, M.A. AND J. W. HADFIELD, O.B.E., H.D.A.

Revised and enlarged by

G. H. THORP, M.Agr.Sc.

1961
WHITCOMBE AND TOMBS LIMITED

FW

FIRST PUBLISHED 1919
SEVENTH EDITION 1961
(*Extensively revised*)

Copyright © 1919 Whitcombe and Tombs Ltd

231920

PRINTED AND PUBLISHED BY
WHITCOMBE AND TOMBS LIMITED
CHRISTCHURCH AUCKLAND HAMILTON HASTINGS LOWER HUTT
WELLINGTON TIMARU DUNEDIN INVERCARGILL
LONDON MELBOURNE SYDNEY GEELONG PERTH

Preface to the Seventh Edition

THIS BOOK was first published in 1919. To each of the six editions that have since been printed many corrections and additions were made in an effort to keep the subject matter up to date. Despite this, the science and practice of agriculture has changed so radically and advanced so rapidly in recent years that it has become necessary, in this seventh edition, to make a far more extensive revision than any of those that preceded it.

In this connection the publishers were fortunate in obtaining the services of Mr. G. H. Thorp, M.Agr.Sc., of Otahuhu College, himself a teacher of science and agriculture. In this edition Mr. Thorp has sought to retain the general form of the text, adding features only in order to promote its usefulness as a handbook for pupils and teachers. The needs of the more able pupils have been kept constantly in view.

Additions include: A new introductory chapter covering the history of New Zealand agriculture; two new chapters, one on soil conservation and the other on farm trees; major additions to the chapters concerned with energy of plants, soil, fertilisers, pasture management, diseases, pests, and weeds; and a list of accessible literature and films at the end of each chapter.

Mr. Thorp wishes to make grateful acknowledgement of the assistance given him by the following scientists and scientific institutions in checking and improving his revision: Mr. H. S. Gibbs, Senior Pedologist of the Soil Bureau, D.S.I.R., Chapters 8 and 9; Dr. E. B. Davies, Principal Scientific Officer, Rukuhia Soil Research Station, Department of Agriculture, Chapters 11 and 12; Dr. J. S. Yeates, Head of Agricultural Botany Department, Massey Agricultural College, Chapter 21; several officers of the Plant Diseases Division, D.S.I.R., Chapters 23 and 24; and to the many authors of books and articles consulted and cited.

August, 1961
Christchurch

J. W. HADFIELD

Contents

Preface to the Seventh Edition

		Page
1.	Farming in New Zealand	1
2.	Seeds	8
3.	General Structure of Plants	23
4.	How Plants get Water and Minerals	39
5.	How Plants get Energy	57
6.	Food Storage and Growth	82
7.	Flower and Fruit	96
8.	The Formation of Soil	121
9.	Soil Texture	142
10.	The Physical Properties of the Soil	156
11.	The Chemical Properties of Soil	167
12.	The Biological Properties of Soil	183
13.	Fertilisers and Lime	195
14.	The Selection and Valuation of Fertilisers	228
15.	Tillage and Drainage	237
16.	Soil Erosion and Soil Conservation	249
17.	Grasses, Clovers and Pastures	258
18.	Pasture Management	295
19.	Farm Crops	322
20.	Conservation of Fodder	359
21.	Farm Trees and Shrubs	372
22.	Reproduction	386
23.	Diseases of Plants	399
24.	Pests of Plants	431
25.	Pruning	460
26.	Weeds	471
	Appendix	494
	Index	498

A farm in the Waikato district. Note the homestead, farm buildings, livestock and shelterbelts

1

Farming in New Zealand

THE HISTORY of agriculture in New Zealand is a record of great achievement in overcoming many difficulties, for our country, though endowed with a climate very suitable for agriculture, has little naturally fertile soil and much very hilly country.

Agriculture in New Zealand was started by the Polynesians, the Maoris and their predecessors, the moa-hunters. After the first white men landed on the shores of New Zealand in 1769 Captain Cook reported the existence of large coastal cropping areas of up to 200 acres in kumara, taro and yam. Considering that the Maoris used only wooden and stone tools this is remarkable. Helped by the early missionaries the Maoris were quick to make use of the potato introduced to them first by Captain Cook and later by the whalers. Early in the 19th century the potato had become a major item in their diet and was an article of trade with visiting ships. Maori agriculture continued to develop and reached a high level in the Waikato, Bay of Plenty and Rotorua districts where, just prior to the Maori Wars (1860–72), several thousands of acres of native land were in potatoes, wheat, maize and kumaras.

European agriculture in New Zealand was started in 1814 by the Rev. Samuel Marsden at his, the first, mission station in New Zealand at the Bay of Islands. Apart from the mission stations, there was no organised agriculture until after the signing of the Treaty of Waitangi in 1840. Organised settlement of Otago took place in 1848 and of Canterbury in 1850. In these provinces the open native tussock grasslands invited grazing and soon pastoral farming on a large scale developed to the Australian pattern. Near the centres of population throughout New Zealand mixed farming developed to supply the needs of the townsfolk. There were, in those days, no special kinds of farming like dairying and fruit-growing. Most settlers raised a great variety of crops and livestock, and their wives not only cooked and sewed, but also spun, knitted and churned. Just before the Maori Wars, Auckland, then the largest centre of population, produced more wheat than Canterbury.

With the advent of the Maori Wars farm production in the North Island waned. Then the discovery of gold in Otago in 1861 created a great demand for food which was supplied from the cultivated plains of Canterbury and Otago. The flat nature of the country enabled roads, railways and towns to be built rapidly. After 1870 alluvial gold production declined and many gold miners became farmers. The result was that by the year 1875 cropping was the main agricultural activity in New Zealand, and wheat and oats, along with wool, hides and tallow, were the main exports. The only way surplus sheep could be properly disposed of at that time was to boil them down for tallow. Grain exports reached their peak in the period 1883–90 when they constituted about one-quarter of the total value of farm exports. The cessation of the Maori Wars allowed farmers in the North Island to fell and burn the native bush which covered most of the island and to sow pasture seeds in the ashes of the burn. 'Between 1870 and 1880 three million acres of native bush was turned into pasture.'

The year 1882 can be regarded as a turning point in New Zealand's agricultural history, for it was in that year that the first successful shipment of frozen meat was made from New Zealand to England. On the day of its arrival in England, the event was called 'a prodigious fact' by that famous English newspaper, *The Times*. Frozen meat exports from New Zealand in the following year were to the value of £118,000. The New Zealand farmer of those days was not, however, to gain much more of the fruits of this wonderful development until many years had passed. Prices for the main export products fell markedly during the following years, resulting in the depression of the 'eighties, when many farmers were in straightened circumstances.

At the turn of the century there was a return to more stable prices and, from that time until 1914, prices for our exports rose steadily and farming developed rapidly. Then it was that refrigeration had its effects. The higher-priced farm products chiefly meat, butter and cheese, ousted the lower-priced products, wheat and oats, from our flow of exports. In 1891 frozen meat exports realised over £1 million and in 1921 frozen meat and butter realised about £11 million each and the value of cheese was not far behind. Instead of growing crops directly for export, farmers used them mainly to feed livestock which produced goods for export. Today 75 per cent of the arable crops grown in New Zealand are used to supplement pastures for animal feeding. Also, as a result of refrigeration, instead of depending only on wool, hides, skins and tallow for value from animals, farmers were able to promote the produce of the milking cow, the milking ewe and the milking sow. There was ushered in the change from 'dry' stock farming to 'wet' stock farming, a change that has continued and widened in scope up to the present time as pastures have grown in area and improved in quality. In 1920 dry ewes and wethers represented about one-quarter of the total sheep in New Zealand, but in 1945 they were only one-tenth of the total sheep, and in 1955 only one-thirteenth. As Mr. A. H. Cockayne put it at the 1956 International Grassland Conference—'The development of refrigeration brought about the sex factor in grassland utilisation. Because female livestock, under our conditions have a low winter feed requirement and a high spring and summer requirement, their feed requirements coincide with our maximum grass growth.'

New Zealand's success in this 'wet' stock farming is largely due to the favourable climate with its mild winters and ample rainfall ideal for pasture growth, and to the cheapness of pasture which the animal gathers for itself all the year round.

Visitors from northern hemisphere countries are struck with three major contrasts between our farming and theirs. New Zealand farmers do not feed their animals indoors during the winter; there is little or no feeding of meals and other concentrated feeds to cattle and sheep; and there is little artificial nitrogenous fertiliser applied to pastures, for clovers supply the nitrogen needed in most of our pasture.

So successful have we become with this kind of farming that we have become highly specialised producers of a few farm export products. Many other farm products are not being produced in sufficient amounts for our own needs. Wheat, oats and sometimes potatoes have to be imported despite the fact that our yields per acre of these crops are among the highest in the world and that the fertility of our arable lands is increasing steadily.

Here are some of the highlights in our agricultural history:

1821. The first land in New Zealand to be ploughed was at Kerikeri, Bay of Islands.

1831. The first farm in New Zealand was established at Waimate North by the Church Missionary Society.

1850. Large-scale settlement of New Zealand began, and sheep were established in many parts of the country. Wool became an important export.

1870–1920. A great increase in the area of our sown grasslands by turning native bush, chiefly in the North Island, into pasture at the rate of about 300,000 acres a year.

1882. The first export of frozen meat from Dunedin. This resulted in New Zealand farmers changing from mainly 'dry' stock farming to mainly 'wet' stock farming.

1884. The first Government Act to prevent the introduction of diseases and pests, the Codlin Moth Act.

1892. The formation of the Department of Agriculture and the beginning of farmer advisory services, quarantine regulations for livestock, plants and produce, and the introduction of cow testing.

1909. The first cow testing association was formed.

1910. Publication of the *New Zealand Journal of Agriculture* started. Increased use was made of agricultural advisers to help farmers. Many diseases of crops and livestock were prevented or controlled. Topdressing of pastures with fertilisers became more common.

1920. Large farms were being subdivided, making for closer settlement and increased agricultural production. There was a notable increase in the use of mechanical aids to farming, especially with electric motors, farm tractors, and milking machines. Topdressing of pastures was becoming more widespread, and the use of herd recording to improve dairy herds was becoming more common.

1930. The development of superior strains of pasture plants and their assured supply to farmers by certification was under way. Marked improvement in the grazing management of livestock.

1935. The discovery that deficiency of the element cobalt in some soils, especially those of the Central Plateau of the North Island, was the cause of the troublesome disease called 'Bush Sickness' led to large areas of land, hitherto incapable of being farmed, being developed into good farming land.

1939. Setting-up of the Animal Research Division of the Department of Agriculture to co-ordinate departmental research into animal diseases, husbandry, breeding and nutrition.

1940. The use of sire survey and progeny selection to improve dairy cattle started and later extended to improve some sheep.

1950. The application of fertilisers and seeds to unploughable hill country by using aeroplanes, and the dropping of fencing materials from aeroplanes for the closer subdivision of the improved pastures.

Greater emphasis on the study of trace elements necessary in the nutrition of animals and plants.

Large-scale application of artificial breeding to dairy cattle.

Today, New Zealand is the largest meat exporting country in the world. This meat, together with that used for home consumption, comes from a livestock population of about forty million sheep and six million cattle, which provide in addition much wool and dairy produce to swell our exports. Over 90 per cent of the value of our exports comes from our pastures. It is these exports which pay for our imports such as machinery, cloth, vehicles and raw materials for our secondary industries. Because of this and because our exported products are in strong competition with those of other countries and our markets are far away, the New Zealand farmer, if he is to be successful, must keep down his production costs, maintain high quality and produce a wide variety of goods.

Farm production must also increase in quantity because it has been estimated that in the foreseeable future, there will be an increase in the population of New Zealand of about 50,000 people a year. Besides the feeding of the extra people there will be needed more exports to pay for more imports. This means that the average annual increase in livestock ruling over recent years must be more than doubled. To achieve this many poor pastures will have to be improved by ploughing and resowing; more pastures must be topdressed, subdivided and better managed; the fertiliser requirements of our soils, especially with regard to trace elements, must be studied more fully; diseases and pests of animals and plants must be better controlled; the draining of damp soils and the irrigation of dry soils must be extended; the conservation of our soils especially on the steep hill country must be more widely applied; more waste land must be brought into production.

In regard to waste land, there are many thousands of acres of land in scrub, fern and secondary growth that are being turned into pasture with the aid of modern equipment and modern knowledge of soil requirements. Not only is this waste land in large areas such as the Central Plateau of the North Island, the sand dune country of the west coast of the North Island and the ironstone country of Northland, but also in many existing farms throughout New Zealand. Perhaps in the more distant future enterprising New Zealanders will emulate the Dutch and turn the large areas of mudflats and tidal estuaries into pasture. There is no doubt that there should be ample opportunity in New Zealand for those with energy, skill and knowledge to find useful positions in farming.

Animal products must be of high quality and low in cost because an overseas buyer—usually a housewife—wants the best quality she can get for her money, and her purse is not always deep. Because the consumer is always right, the New Zealand farmer must also give the buyer what she wants in form and flavour, not what he thinks she ought to want, or what she used to want.

Farm production must be in variety, because a slump in the value of one product will not have such a marked effect on farm income if there are several products, as if there are only one or two.

Most farmers in New Zealand have the privilege of farm ownership. It is an axiom of living, that with privileges there are responsibilities. The greatest responsibility on the shoulders of New Zealand farmers is to conserve their land so that future generations will be able to enjoy the fruits of it at least as well as they are enjoyed today.

FOR FURTHER READING

Primary Production in New Zealand,
N.Z. Department of Agriculture
New Zealand Official Year Book,
N.Z. Government Printer
Farming in New Zealand,
N.Z. Department of Agriculture
Pasture Production in New Zealand,
N.Z. Department of Agriculture

FILMS

(The National Film Library)
'Farming in New Zealand'
'Tribute to Achievement'
'Carpet of Grass'
'Science and Agriculture'

2

Seeds

THE COMMONEST method of raising plants is by sowing seeds. A knowledge of their structure and early development is necessary if the seeds are to be used to the best effect.

STRUCTURE OF BROAD BEAN

If an almost ripe broad bean pod is opened each seed is found attached to the case by a short stalk—the *funicle*—through which nourishment from the parent plant passed and enabled the seed to develop.

When a seed soaked in water for about twelve hours is examined the following parts are seen (Fig. 1):—

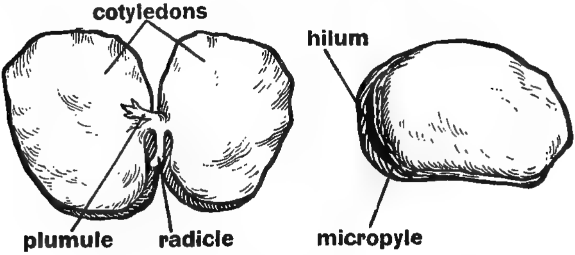


FIG. 1. Structure of broad bean seed

On the outside a tough smooth skin, termed the *seed coat,* having a black scar at one end, which marks where the seed was attached to the pod, and which is called the *hilum.* If the soaked seed is carefully wiped dry and then pressed between finger and thumb water oozes through a very small hole termed the *micropyle,* which is quite close to one end of the hilum.

On slitting round the edge with a knife the seed coat can be stripped off. The inner portion is easily divisible into two large fleshy halves called *cotyledons.* To these is attached a somewhat cone-shaped body, which is the young plant or *embryo.* The part lying between the cotyledons and above the point of attachment is the *plumule* or young shoot. When examined with a lens the undeveloped leaves may be seen. Immediately below the point of attachment to the cotyledons is the *hypocotyl,* which is a very small piece of stem not easily distinguishable from the *radicle* or young root, which is continuous with it, and which projects into the cavity just under the micropyle.

THE MAIZE GRAIN

The maize grain, though not a true seed, may be taken as typical of the second great class of seed-bearing plants.

The grain is roughly wedge-shaped, and has an apex which marks the place of attachment to the cob. An opening may be located at the apex by placing a dry grain in hot water, when a bubble of air comes out. The opening corresponds with the micropyle of the bean. On one side of the grain is a depression, thumbnail-shaped, or more or less triangular. If a well-soaked grain is cut so as to divide the depression into two equal portions the parts as shown in Fig. 2 will be seen. About half the grain consists of floury or horny material, which is called *endosperm.* Directly under the depressed area is a structure, one portion of which next to the tapering end of the grain is the *radicle,* the other end being the *plumule,* forming a straight line with the radicle. Together they form the *embryo,* which is separated from the endosperm by a tough shield-shaped body which is the *cotyledon.* The foregoing observations show that the differences between a grain of maize and a bean seed are two—

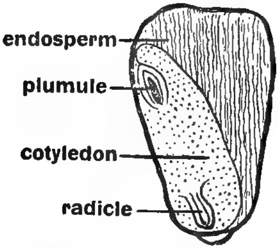


FIG. 2. Structure of maize grain

1. The bean has two cotyledons, the maize has one. Practically all farm plants belong to a subdivision of the plant kingdom known as Angiosperms, and these are divided into two classes—

(a) MONOCOTYLEDONS—having only one cotyledon in seed and seedling, e.g., maize, wheat, ryegrass, onion, daffodil, tulip.

(b) DICOTYLEDONS—with two cotyledons in seed and seedling, e.g., bean, turnip, mangel, oak, clover.

2. The maize has endosperm, the bean has no endosperm. Seeds with endosperm are called *endospermic,* those without it are *non-endospermic.*

Exercise 1.—Take a sufficient number of broad beans to enable two seeds to be given to each member of the class; soak them in water all night. Examine them next day and make drawings of the parts seen both before and after the removal of the seed coat.

Exercise 2.—Similarly soak and examine a sufficient number of maize grains.

Wheat, barley, and oat grains may be used instead of or in addition to maize grains. Their structure is essentially the same, but they are not so suitable for study because of their comparatively small size.

STORES OF PLANT FOOD

Plants store reserve supplies of food in different organs, and several of these plant foods are found in seeds. The main plant foods are—

1. *Carbohydrates,* such as starch, sugar, cellulose, gums, and inulin. These consist of carbon, hydrogen, and oxygen, the proportion by weight of the two latter being the same as exists in water.

2. *Oils,* like carbohydrates, contain carbon, hydrogen and oxygen, but the proportions of these are different.

3. *Proteins* are nitrogenous compounds, containing *nitrogen,* sulphur, and often phosphorus, in addition to the elements carbon, hydrogen, and oxygen.

These three classes of substances come into existence only through the work of plants which manufacture them for their own special use, but they are of great importance, for directly or indirectly they provide the principal food of mankind and of animals.

FOOD STORED IN SEEDS

1. *Starch,* which is insoluble in cold water, is present in most seeds. It is easily converted into sugar, which though rare in dormant seeds, is, as will be shown later, common in germinating seeds.

TEST FOR STARCH

Exercise 3.—Shake a very little starch in a test-tube of cold water and boil well. Then cool and add a few drops of iodine solution: a blue colour is formed. If much starch has been used a dark blue, almost black, colour will result.

Exercise 4.—Boil scrapings of the endosperms of grains of wheat, oats, maize, barley, or rice and test as above with iodine solution. Also test the embryo of these grains for starch. This can best be done by cutting the grains so as to expose both endosperm and embryo and then dipping the exposed section into iodine solution. The endosperm will become almost black, while the embryo shows a light colour. What does this indicate? Test the cotyledons of peas and beans for starch.

TEST FOR SUGAR

Exercise 5.—(a) Dissolve a little lactose or glucose in some water. Take some of this solution in a test-tube to a depth of half an inch and add Fehling's solution No. 1 to raise the liquid another quarter of an inch in the tube. Add an equal amount of Fehling's solution No. 2. Boil. A brick red precipitate appears. This is the test for sugar. (b) Cane sugar will not give this test directly. Dissolve a little cane sugar in water. Test one portion of the solution as described for lactose. Then to the other half add one or two drops of sulphuric acid and boil for five minutes. Place a piece of litmus paper in the solution, and add caustic soda solution slowly until the litmus turns blue. Then add equal quantities of Fehling's No. 1 and No. 2 as described above, and boil. The brick red precipitate should appear.

Exercise 6.—Test dry seeds of wheat, maize, barley, oats, beans, and peas for sugar. What do you find?

Exercise 7.—Test carrots, apples, parsnips, grapes, lemons, fodder beet, and turnips for sugar.

2. *Proteins* are found more abundantly in the seeds than in other parts, though in growing plants they are abundant in the leaves. Common proteins are albumen which occurs as white of egg, and casein which occurs in the curd of milk.

TEST FOR PROTEIN

Exercise 8.—Put a small piece of the white of a hard-boiled egg in a test-tube. Add a small quantity of strong nitric acid and heat. Note the yellow coloration which changes to orange when excess of ammonia is added. Take care to add the ammonia gradually and cautiously.

Exercise 9.—Test bean and pea cotyledons for proteins.

Exercise 10.—Cut the grains of barley, maize, and wheat into halves and dip these halves into strong nitric acid. Examine for a region of yellow coloration on the exposed surface. This indicates where the protein occurs.

Exercise 11.—Test other seeds, root crops, and animal foods for protein.

3. *Fats and Oils* are found in many parts of plants, but most abundantly in seeds. They contain carbon, hydrogen, and oxygen, and are characterised by a high per cent of carbon and a low per cent of oxygen. They have 2¼ times the food value of starch and sugar. The fats in plants are produced from starch; they

occur as small globules in the cells, and may be removed by heat and pressure, and the use of solvents such as benzine, ether, and carbon bisulphide.

Fat when heated and dropped on glazed paper makes it translucent.

TESTING SEEDS FOR FAT OR OIL

Exercise 12.—Take rape, turnip, sunflower, castor oil, or linseed seeds. Crush (with the end of a pencil or by other means) on a piece of white notepaper. Hold up to the light and note translucent mark formed.

Exercise 13.—Grind linseed or rape seed in a mortar and dry it in a water bath. Put in a test-tube, cover with ether, and cork tightly. Shake the test-tube from time to time, and after a few hours pour the ether into a dish and stand it in a warm place to evaporate. Examine what is left. Keep ether away from a light, and breathe it as little as possible.

The preceding exercises show that food stored in seeds as proteins, fats, and carbohydrates is found sometimes in the fleshy cotyledons, sometimes in the endosperm. These foods are all *insoluble* and unable to pass through the cell walls. In nature, seeds often lie dormant in the moist soil for long periods, and if the stored food were soluble it would gradually diffuse through the seed coat, and thus the embryo would be deprived of its reserve of food.

The amount of food stored depends chiefly on the size of the seed. The food supports the young seedling till it has established itself. If small seeds are planted deeply the store of food is apt to be exhausted before the seedlings have established themselves. Hence a fine seed bed which allows of shallow sowing is desirable for small seeds. It must be remembered, however, that shallow-sown seeds are less sure of obtaining the continuous supply of moisture which is so necessary.

GERMINATION

Seeds, except dead useless ones, are not absolutely inactive; they are merely living quietly, i.e., they are in a sleeping or dormant state. When under certain conditions they awake into greater activity and resume their development they are said to germinate. Germination includes all the changes that take place till the young plant establishes itself, and the *conditions necessary* are—

1. A supply of *moisture.* Seeds may be kept for years in a

dry place without awakening, but if moisture is provided and other conditions are suitable germination will at once begin.

The fact that seeds germinate on moist paper or flannel shows that soil is not necessary. That light is not necessary follows from the fact that seeds buried in the soil germinate, though they receive no light. The development of many seeds is slower in light than in darkness. However, others such as browntop require some light in order to germinate.

Exercise 14.—Soak seeds of maize, wheat, oats, beans, peas, in water, some for 2 hours, some for 24 hours. Carefully dry these, taking care not to break the skin, and put them in dry bottles. Observe the seeds from day to day, and note your results.

2. *Warmth* is necessary. This is the reason why, in cool climates, seeds will lie in the ground during the winter without becoming active. Allowing for certain exceptions, there is a maximum temperature above which germination will not take place. In most cases it is about 115° F.; there is a minimum temperature below which no germination occurs—about 40° F.; and there is also an *optimum* temperature at which development is most vigorous. The optimum is between 75° F. and 90° F., according to the plant. This is important, because of the fact that the soil temperature is frequently below this point, and hence there is a call for practices which will produce warmer soils.

The seeds of most plants of temperate climates germinate in early spring when the temperature is about 45° F. to 50° F., e.g. many vegetables and grasses and clovers.

The following seeds which sprout at about the time plums and peaches blossom (i.e., at about 45° F.) may be planted early in spring, and some of them if planted in autumn live through the winter:—

Barley
Beet
Cabbage
Carrot
Cauliflower
Clover (red and crimson)
Grasses (most)
Kale
Lettuce
Oats
Onion
Parsnip
Peas
Phlox
Petunia
Radish
Rye
Stock
Sweet Pea
Turnip
Wheat

The seeds of other plants more sensitive to cold germinate to better advantage in late spring at temperatures of 55° F. to 60° F.

The following sprout at about apple blossom time (i.e., at 60° F. in the shade):—

Beans (Soya and Runner)
Cow pea
Cucumber
Lucerne
Pansy
Maize
Melon
Mignonette
Millet
Pumpkin
Sorghum
Squash
Sudan Grass

To germinate satisfactorily, nearly all seeds require a daily fall in temperature from warm to cold (day and night temperatures) even when germinated artificially.

3. *Air (oxygen)* is necessary. Evidence of this is provided by the fact that weeds buried some inches in the soil for periods up to 100 years, germinate only when brought up to the surface by cultivation.

Is Air Necessary for Germination?

Exercise 15.—Soak some seeds (beans or maize suit well) for 24 hours. Dry them. In one half-pint bottle place enough seeds to cover the bottom of the bottle two seeds deep; label it A. Fill another similar bottle seven-eighths full of them; label it B. Tightly cork both bottles and let them stand for several days. What do you notice?

To Show Whether Oxygen is Required for Germination

Exercise 16.—In one end of each of two U-tubes place a few barley or mustard seeds on moist cotton wool or rag. Procure two gas jars. Into one add a few inches of water and in the other a few inches of sodium or potassium pyrogallate solution. Place one of the U-tubes in each jar with the open end dipping into the liquid. Then with air-tight corks (preferably rubber) block up the end containing the seed. Note what happens and explain the results. What does this experiment indicate about seed beds in soil? (For preparation of pyrogallate solution see Appendix.)

Changes in Germinating Seeds

1. *Water is absorbed,* the seeds swell and become softer; in swelling they exert considerable pressure. The water enters the seed mainly through the micropyle, but some also enters through the seed coat. At the same time some solid matter, namely cane sugar, passes out in solution to the water. This explains why a quantity of grain which has been damaged by water shows a loss of weight when it is dried again. In certain plants, notably members of the clover family, a waxy secretion develops at maturity on some of the seeds in such a way as to form what are known as 'hard' seeds. Being impervious to water, these

seeds cannot germinate until the secretion either softens or is mechanically scratched. Such seeds may remain hard in the soil for only a few months or for many years, and may account for the appearance of white clover plants in fields where none was sown.

A few hours before sowing certain seeds, e.g. wattle and tagastaste, boiling water is sometimes poured over them, and allowed to cool. The object is to assist the penetration of water.

To find how Water Enters the Seed

Exercise 17.—Weigh two similar lots (20 in each) of dry seeds. Seal the micropyles of one lot with plasticine, tyre solution, or vaseline. Soak the two lots in water. Wipe the sealed and the unsealed seeds daily and weigh each lot to compare the rate at which each is absorbing water. Calculate the percentage by weight of water absorbed between weighings.

2. *Respiration* takes place, i.e., germinating seeds change the air in the same way as an animal does, by breathing. The oxygen, which we have already seen to be necessary, combines with compounds containing carbon, e.g., starch, thus supplying the energy needed by the growing embryo. In this process carbon dioxide is given off and heat is produced. This is to be expected, for respiration involves a chemical change exactly similar to, except that it is slower than, that which takes place in burning.

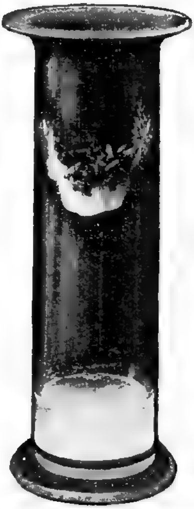


Fig. 3. Apparatus set up to determine whether germinating seeds give off carbon dioxide

To Find whether Germinating Seeds give off Carbon Dioxide

Exercise 18.—Place about 2 inches of clear limewater in a gas jar. Take a piece of wire gauze which, when forced into the jar will support itself and serve to hold some damp cotton wool or blotting paper. On the latter place some soaked barley or mustard seeds, as shown in Fig. 3. To exclude air, cover the jar with a ground glass lid smeared with vaseline. Have two similar jars as controls, in one have seeds from the same sample dry, and in the other no seeds. After about a day compare the appearance of the limewater in the three jars. In which jar is the change in the limewater greatest and why?

3. *Digestion of Stored Food.*—When germination occurs the reserve food in the seeds must travel from cell to cell through the cell walls to the place where it is needed, and to do this it must be changed to soluble and diffusible material, i.e., it must be digested. Starch, oils, and cellulose are changed into sugars; proteids into soluble nitrogenous compounds called peptones. All these changes are due to substances known as *ferments*. The one that acts on starch is diastase, and is very similar to the one in saliva. Even dry seeds are breathing slowly and using up part of their substance. The stored insoluble substance being dry, cannot be utilised by the embryo which has to depend on spare material possessed within itself. Hence, as soon as this spare material is exhausted, the embryo perishes even though the rest of the seed is perfectly sound. Seeds buried in the ground often retain their vitality much longer than ones stored in the air, because the extra moisture available enables the embryo to draw upon the food stored in the endosperm or cotyledons instead of dying as soon as it has used up its own stock. Long before the death of seeds their vigour becomes weakened greatly through age.

Exercise 19.—Mix a little starch paste, made with cold water, in a test-tube with saliva. Keep it at the body temperature for a few minutes, then add Fehling's solution, and boil. Explain what you see.

Exercise 20.—Pour 20 c.c. of a very thin starch paste into a test-tube, add 3 or 4 c.c. of diastase of malt. Keep it at a temperature of 140° F. and test for starch at intervals of five minutes. Note your results and conclusion.

Exercise 21.—Test dry barley and other seeds for sugar; then test some which have germinated but have not yet become green. These can be obtained by sowing fairly deeply in moist sand or sawdust.

4. *How Seedlings Emerge from the Soil.*—In many cases the tender young shoot is protected from injury by the tip bending backwards in a loop as it pushes upwards. Shoots push upwards with considerable force—the broad bean is known to have exerted a force equal to 80 lb. to the square inch. By this force seedlings are able to grow through hard and stiff soil.

In the case of most flowering plants the cotyledons come above ground, become green, and do the work of foliage leaves for a time. Such cotyledons are called *epigeal,* e.g., pumpkin, French bean, sunflower, mustard. In other cases the cotyledons do not come above ground, but remain in the seed coat and simply supply food to the young plant. These are called *hypogeal,* e.g., broad bean, garden pea, scarlet runner.

In monocotyledons, e.g., maize and wheat, the young shoot which pushes straight upwards is protected in the early stages by a tubular sheath which remains closed till the tip of the shoot is well out of the soil, and which finally bursts at the apex, and frees the first foliage leaf. The shield-like cotyledon remains in its original position, being of use simply to digest and absorb the food stored in the endosperm. The young root which first appears bears rootlets, but it does not, as in the bean, etc., give rise to the root system.

Exercise 22.—Place in a box of damp sawdust or sand some broad bean seeds. Every second day for about a fortnight transfer one of these seeds into a large test-tube containing a 4 per cent formalin solution (1 part formalin to 9 parts water). Then make each test-tube air-tight. If labels are attached showing the period of germination of the seeds, and the tubes arranged in order on a stand a record of the germination stages for future reference is obtained. Pumpkin seeds or French bean and maize, or wheat, being typical of other modes of germination, should be similarly studied.

FARM SEEDS

Few things are of greater importance to the farmer than good seed. By the use of inferior seed the yield suffers, weeds and sometimes diseases are introduced. The expenses, (rent, cultivation, harvesting, etc.), are nearly the same whether the crop is large or small. The difference in cost between good and inferior lines of seed is often small, but the difference in yield from them is sure to be great. *The best seed is never too good* is a sound practical maxim. Cheap seed is not necessarily inferior, but it practically always is so. On the other hand high price is not necessarily a guarantee of good quality.

Soon after inferior pasture seed has been sown the area often has to be ploughed again and resown. This means loss to the farmer in production during the renewal and in the expenses of the renewal. If the farmer is on unploughable hill country, renewal is difficult or impossible.

To determine the quality of a line of seed, attention must be paid to purity, percentage of germination, speed of germination, and origin or strain.

1. *Purity.*—Anything other than the particular species or variety of seed that the purchaser seeks is regarded as impurity. In certain instances impurity cannot be detected, e.g., it is practically impossible to distinguish between the different varieties

of swedes, but in the majority of cases the impurity can easily be seen. Impurities are of special importance when they include objectionable weed seeds, such as ragwort, dodder, sorrel, docks.

In an analysis, a weighed portion of the seed-sample is usually broken up into four separations, and the proportion of each expressed as a percentage by weight.

(1) Pure seed—mature, whole-grained seed.

(2) Other crop seed, i.e., ryegrass in cocksfoot, white clover in ryegrass, etc.

(3) Weed seeds—the seeds of all agriculturally useless plants.

(4) Inert matter—husks, straws, soil particles, and broken seeds.

In an official analysis, the weed-seed content of a seed-sample is also expressed as the number of seeds per ounce of sample, which provides a better indication of the degree of infestation, particularly of noxious or troublesome weeds.

To Find the Purity of a Sample

Exercise 23.—Mix the seed well. Take a representative sample of from 1 to 5 grams according to size of individual seeds. Weigh this carefully on a chemical balance. Spread it on stiff paper, and carefully sift out all foreign seeds and matter. A record should be made of the weed seeds present. The percentage of purity is calculated thus:—

grams.
Line 1—Weight of seed taken =
Line 2—Weight of pure seed obtained =

Percentage of pure seed = $\frac{\text{line 2}}{\text{line 1}}$ of $\frac{100}{1}$

2. *Percentage of Germination.*—Purity is not sufficient; it is necessary also to determine what numerical proportion of the seeds are capable of growth. Poor germination may be due to imperfect development of the embryo during ripening, to mechanical injury, to too high a temperature, to age, or to excess of moisture in store. The germination test is applied to the pure seed, that is, the residue after the impurities have been removed.

To Test Germination Capacity

Exercise 24.—Moisten a piece of thick filter paper, blotting paper, flannel, or felt without making it dripping wet, and place it on an ordinary plate or saucer. Take 200 seeds, distribute them evenly on the moist material, and cover them with a lipped beaker turned upside down. Place this in a warm room. A temperature of about 60° F. is suitable for most ordinary seeds. During the test, the seeds should be moistened if necessary. Those germinating should be removed as soon as the shoot shows itself, and the number removed each day noted.

The *time to allow* for the test varies with the kind of seed.—An interim or progress report is generally furnished, but the test is not completed till the following periods have elapsed:—Cereals, clovers, peas, turnips, 10 days; ryegrasses, 12 days; carrot, parsnip, mangel, timothy, 14 days; chewings fescue, brown top, crested dogstail, cocksfoot, 18 days; and from 21 to 28 days for other grasses not mentioned.

For large seeds like lupins and peas and for large irregular seeds such as mangels, damp sand should be used, as only in this way can an even supply of water to the seed be maintained. Most seeds germinate better in darkness than in light, but some germinate better in light.

At the end of the test, the number of living seeds out of the number tested is known, and from this the number of living seeds in every 100 can be calculated, thus getting the percentage of germination. For example, if 178 germinate out of 200 seeds tested, percentage of germination is $\frac{178}{200}$ of $\frac{100}{1}$ = 89 per cent.

Age in relation to Germination. Twenty kinds of seed tested gave an average of 73 per cent germination when fresh and 19 per cent ten years later. Seeds of any particular crop show marked differences in their ability to remain viable, for the conditions under which they have been harvested and stored have a direct effect. Seed kept dry will remain viable for many years, but if kept in an ordinary moist atmosphere, a process almost equivalent to slow germination takes place, there is a wastage of food reserves, and a loss in germination. This emphasises the necessity for drying seed thoroughly at harvest, and keeping it dry during storage.

The ability of seed to retain vitality during storage varies considerably for the different kinds of seeds; a few commence to deteriorate within a year after harvesting, others may live up to ten or more years. Agricultural seeds, if kept under ideal storage conditions, may retain their germination for the following periods:

Ryegrasses	3–4 years
Cocksfoot	3–4 years
Crested dogstail	1–2 years
Chewings and other fescues	1–2 years
Brown top	2–3 years
All clovers, lucerne, etc.	4–5 years

Dormancy. Some newly harvested seeds, although apparently ripe when harvested, exhibit dormancy, a condition which prevents the germination of living seed when other conditions such as moisture and temperature are favourable. During some months' storage the seed slowly matures and germinates normally when sown. Examples of plants in which dormancy commonly occurs are several varieties of oats, Cape barley, some varieties of wheat, New Zealand spinach, and many tree seeds. This is the reason why, in some cases, one-year-old seed is offered by merchants for autumn sowing.

Dormancy, like seed hardness, usually follows unusual seasonal weather conditions and is considered to be a natural provision for delaying germination until the following or later seasons.

3. *'Pure Germinating Seed'*.—A term used in the seed trade to express the percentage by weight of a line of seed which can be expected to germinate. The percentage of purity indicates the number of pounds per 100 of pure seed in a line; the percentage of germination indicates the number per 100 pure seeds which will germinate. Neither percentage indicates just how much of the line will grow, which can however be exposed as a third percentage, the *pure germinating seed,* which is estimated as follows:

Pure seed:

80 per cent = 80 lb. per 100 of line.

Germination:

90 per cent = 90 seeds per 100 of pure seed.

$\therefore$ $^{90}/_{100} \times 80$ lb. = 72 lb. in 100 lb. is the true germination of the line under test.

By calculating the *Percentage of Pure Germinating Seed* of samples we are able to compare the relative cheapness or dearness of seed. For example, two samples labelled A and B are offered at 17 pence and 20 pence per pound respectively.

The purity of A is only 80 per cent, the germination capacity 70 per cent.

The per cent Pure Germinating Seed is, therefore

$$\frac{80 \times 70}{100} = 56 \text{ per cent.}$$

B is 90 per cent purity and 85 per cent germination capacity; its per cent Pure Germinating Seed is

$$\frac{90 \times 85}{100} = 76.5 \text{ per cent.}$$

The prices should therefore be in the proportion 56 to 76.5.

Hence when B is quoted at 20d. per lb. A should be at $\left(\frac{56}{76.5} \text{ of } 20\right)$ d. = 15d. approx.

Since A is quoted at 17d. per lb. sample B is the better value.

The quantity of seed to sow per acre depends on the percentage of pure germinating seed as calculated above; the statement of so many pounds per acre is useless unless we know the quality of the seed—one lb. of seed with 96 per cent of pure germinating seed is equal to 3 pounds with 32 per cent of pure germinating seed.

4. *Speed of Germination.*—It is necessary to distinguish between the mere capacity for germination and the rate of its progress, as what we desire is rapidity and uniformity of speed in germination. Slow development usually indicates constitutional weakness caused by harvesting too early, by poorly nourished parent plants, or by exposure to excessive heat or moisture. Young plants are delicate in any case, and anything checking their progress gives opportunity for attacks by insects and fungi; and unfavourable conditions of soil or climate affect most severely the slow weakly seedlings.

NOTE.—To estimate the agricultural value of a line of seed containing 'hard' seeds (see p. 13), a proportion of the hard seeds present are counted as if they had germinated. In the case of white clover seed the proportion is one-third. In good years, when seeds have ripened thoroughly, the percentage of hard seeds is high, and they may be taken as a partial indication of good quality. Dry, hot conditions will also increase the proportion of hard seed.

In testing as described for the germinating capacity a record of the speed of germination will be obtained by recording periodically the number that have germinated.

5. *Origin and Certification.*—There has always been a great deal of controversy regarding acclimatised seed, but the modern interpretation of the term 'origin' refers primarily to strain. In such species as cocksfoot, perennial ryegrass, white clover, and red clover, there are several strains. These strains vary considerably in agricultural value because they vary in productivity, longevity, and adaptability to certain environmental conditions. It is no longer sufficient to buy seed of a particular species; the strain of that species must be stipulated. To enable this to be done the superior strains of certain species are officially certified by the Department of Agriculture and are sold in sealed bags with a descriptive tag attached. (See Chapter 10.)

6. *Bushel Weight.*—The weight of a measured bushel of seed is frequently an indication of its quality. Pinched seed has a lower bushel weight than plump seed. In oats and many grasses it may be an indication of the proportion of kernel to husk but may also indicate severe machine dressing which has removed a large proportion of the husk. Wheat has a higher specific gravity than water and a high moisture content is reflected in a low bushel weight. A special type of weighing machine, known as a chondrometer, is used in determining bushel weights.

Some seeds are bought and sold at so much per lb., cwt., or ton, as for example clover, turnip, linseed, brown top and many others. Most cereals and some grass seeds are sold by the bushel as in wheat and ryegrass. In these cases each grain has a standard bushel weight as follows: Wheat 60 lb., oats 40 lb., barley 50 lb., lupins and peas 60 lb., maize 56 lb., and grass seeds 20 lb. Ryecorn is officially 56 lb. but the trade uses 60 lb. Thus the purchaser of one bushel of wheat, maize or ryegrass receives respectively 60 lb., 56 lb., and 20 lb. regardless of the measured bushel weight of such seeds. For example the measured bushel weight of perennial ryegrass may well be 30 lb. but the purchaser of a bushel receives only 20 lb.

7. *Subsidiary Characters.*—The characters of chief importance in determining the value of seeds have been mentioned above, but there are other factors worth consideration. These are:—

(a) *Form.*—Well ripened seeds exhibit plumpness and rotundity of form; shrivelled, puckered seeds may be attributed to a check in development through crop starvation, drought, or disease, and the seeds may be expected to be of low vitality.

(b) *Colour.*—Mature seeds are usually of uniform colour—red clover and peas being exceptions. Nearly all immature samples show a tinge of green—this is particularly the case with clover and lucerne.

Cabbage, turnip, and swede, which are dark brown or black, show a paler brown or reddish tinge when unripe; the purple colour of red clover changes to a foxy red with age, and yellowish seeds, such as lucerne, become brownish.

(c) *Smell.*—Some seeds when fresh have a characteristic smell which is lost with age—carrots and parsnips are typical cases. New oats have an earthy smell which is absent from older grain.

A musty smell justifies suspicion as to the quality of a sample, and is an indication of bad conditions during harvesting, stacking, or storage.

NOTES.—Beet, N.Z. Spinach and mangel 'seeds' are really clusters of fruits consisting of corky tissue in which 1 to 5 small seeds are embedded. This explains why the seedlings of these crops appear in groups, thus making 'thinning' necessary. It also warns against sowing the 'seeds' too deeply, for the size of the 'ball' is much greater than that of the seed inside. The germination of beet and mangel seed is expressed as a percentage of the balls.

READING

N.Z. Journal of Agriculture,
May 1957, May 1956, March 1954,
September 1953

Primary Production in New Zealand,
N.Z. Department of Agriculture

Grasslands of New Zealand (Chapter 13)
Levy, Sir E. Bruce

Pasture Production in New Zealand,
N.Z. Department of Agriculture

Agricultural Botany,
Yeates and Campbell

3

General Structure of Plants

ALL PLANTS, except those of the lowest form, consist of unions or aggregates of innumerable microscopic structures called cells. The lowest form of plant consists of a single cell. A cell is a more or less cubical or spherical chamber rarely more than 1/100 inch in diameter.

The cell wall consists mainly of a substance called *cellulose* which is solid, elastic, transparent matter, and which acts as a protection to the cell contents. Cellulose forms the framework or skeleton of plants. Its economic value varies; the cellulose of young plants is more easily digested, and hence more valuable for stock feeding than that of mature plants.

CELL CONTENTS

The wall of a living cell is lined with a slimy or jelly-like substance called *protoplasm* which in very young cells entirely fills the cavity. Protoplasm, which is present wherever there is life, is of a complex composition not thoroughly understood, but we know it contains carbon, hydrogen, oxygen, nitrogen, and sulphur. Several denser bodies of protoplasm occur in the protoplasmic mass. The most noticeable and most important of these is called the *nucleus,* which appears to be specially concerned with the reproductive processes. To the smaller, dense protoplasmic bodies plants owe their colours. Some, which are green, are called *chlorophyll-granules,* and give plants their green colour. Others, which are common in the cells of flowers and fruit, are yellow or red; those in underground parts are colourless.

In very young cells the protoplasm fills the whole cell, but later there develops a central space filled with a watery liquid termed cell-sap, which contains various substances, including starch and proteid grains, sugars, oil, and mineral compounds, all of which at some time or other are used as food material by the plant. The substances in the cell-sap give to plants their characteristic taste, for protoplasm and cell wall are tasteless.

CELL DIVISION

In the growing regions of plants an increase in the number of cells takes place as a result of the division of previously existing cells. The nucleus first divides into two exactly similar halves. These separate from each other, and a new cell wall arises between them and divides the cell contents into two distinct parts. The two chambers thus formed from the one parent cell grow and constitute new cells.

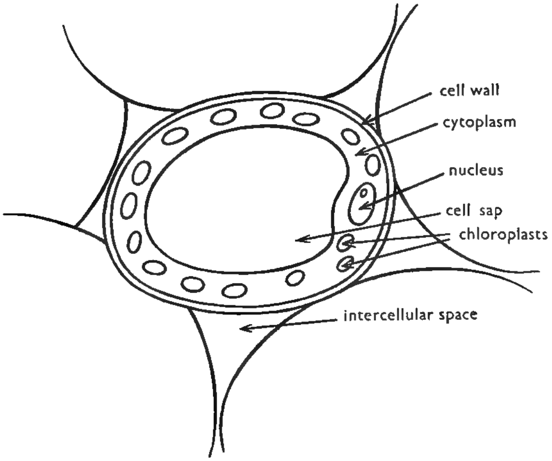


FIG. 4. Diagram of a typical plant cell as in the cortex of a young stem

TISSUES

The cells that constitute a plant are of various forms. Groups or collections of cells similar in development and structure are spoken of as tissues. According to the work which they perform tissues may be classified as—

1. *Formative* tissue, which consists of cells capable of dividing, is the active growing tissue. It is found at the ends of stems and roots, providing for the growth in length of these organs. Where growth in thickness takes place it occurs as a cylindrical layer, and is called *cambium.* It consists of thin cells filled with protoplasm, each possessing a large nucleus.

2. *Epidermal* tissue is the outermost protective layer. It usually consists of a single layer of cells containing no colouring matter. On aerial parts the cell walls are thickened by the development of a substance called *cutin*, which not only gives firmness but also renders the walls almost impermeable to water which, however, finds a passage through numerous tiny openings to be described later. On roots and underground parts cutin does not develop. In many cases a true epidermis is wanting, its work being done by other tissue.

3. *Vascular* tissue is of prime importance in the transport of nutritive fluids in the plant. It is continuous in root and stem as strands or bundles, which pass out into the leaves at various levels and form veins. Because of a woody thickening of the walls of many of the cells the tissue performs a mechanical or supporting function, but the whole tissue is especially adapted for transporting watery solutions.

4. *Ground* tissue, which includes all groups of cells not included in the above tissues. Its structure and functions vary, and will be described in due course.

ROOT STRUCTURE

Knowledge of root structure sufficient for practical purposes can be obtained by examining the carrot root in section. The following structures can be distinguished (Fig. 5):—

1. The *Epidermis*, on the outside, is a thin transparent covering consisting of a single layer of cells. At a point not far from the extreme point of the root many of the epidermal cells are elongated, and form root hairs. The epidermis has a double function, being protective and absorptive (as explained in the description of root hairs). The roots of older, perennial dicotyledons develop a ring of cork from an inner tissue. All the tissues outside this cork, including the epidermis, wither and shrivel, so that the corky layer takes up the protective function of the original epidermis.

2. The *Wood* forms a central cylinder which often wholly occupies the centre of the root. From the wood cylinder arise the secondary roots. In the first season the wood of the carrot contains little or no fibrous matter, but in those which have run to seed it becomes markedly woody and fibrous by the time flowering commences. In general, however, the central cylinder

of the root is distinctly fibrous, e.g., oak, gorse, manuka, and gives the requisite strength and rigidity to the root to enable it to hold the plant firmly against wind.

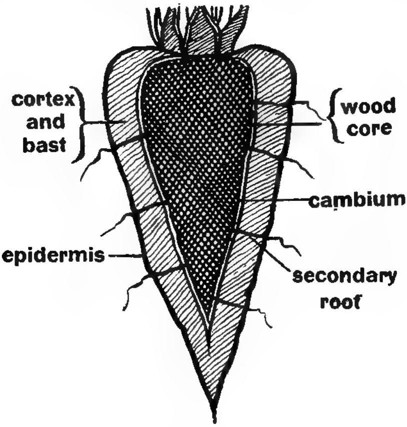


FIG. 5. Structure of a carrot root

3. The *Cambium* occurs as a very thin jelly-like semi-transparent ring just outside the wood. It is the formative tissue producing new cells both on the inside (wood) and on the outside (bast).

4. *Cortex and Bast* consist of the soft thin-walled tissue lying between the epidermis and the cambium, and consisting partly of cells formed by the latter. In the carrot this tissue is developed to an abnormal extent, and serves to hold a reserve store of sugar and other nutrient materials.

STEM STRUCTURE

A perennial woody stem of a dicotyledon exhibits the following parts (Fig. 6):—

1. *Corky bark* on the outside. It consists of cells which generally become filled with air only. Their walls are thin, often brownish in colour and impermeable to water and gases. Scattered over the surface of most woody stems are small brownish or whitish spots termed *lenticels*, which serve for

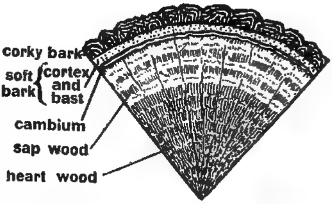


FIG. 6. Old stem in transverse section of dicotyledon

the admission of air. The corky bark protects the interior of the stem from injury, and prevents the loss of water by transpiration. Being a bad conductor of heat, it protects the delicate tissues immediately inside it from excessive heat in summer and frost in winter. In herbaceous plants, i.e., those which are soft and succulent, the corky bark does not appear, its work being carried out by a true epidermis consisting of a single layer of cells, the outer walls of which are much thickened with cutin, which is impervious to water, and which enables the inner tissue to be efficiently protected. An epidermis of this sort originally covers all stems, but in perennial woody stems it is replaced by the corky bark described above.

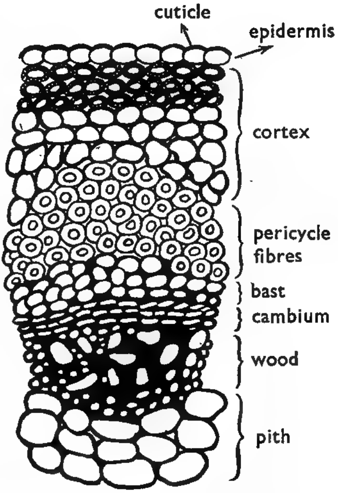


FIG. 7. Part of a transverse section of a bean stem

2. *Soft bark* lies immediately below the corky bark. It consists of cortex and bast. In herbaceous and young perennial woody stems the cortex usually contains colouring matter.

3. The *Cambium* is very similar to that of the root already described. Stem cambium is the most important tissue concerned in grafting and budding. (See Chapter 22.)

4. *Wood*, which occurs as a cylindrical core, usually forms much the greater part of the stem. The amount of wood formed is always very much greater than the amount of bast. Further, the bast consists chiefly of thin-walled tissue which becomes crushed into very thin layers by the pressure which results from the expansion of the wood and the resistance of the bark. Hence in transverse sections the cambium seems to produce wood almost exclusively. A special cambium develops during the healing of wounds. (See next section.)

The core of wood in cross section presents a ringed formation. This is due to the *difference in appearance of the wood produced at the different seasons.* In the spring the cambium produces larger cells with thinner walls than those which it produces in late summer and autumn. Hence the spring wood of soft texture and pale colour gradually passes into the harder darker wood of autumn, which is markedly distinct from the spring wood formed the next season. These separate ring-like zones are called *annual* rings, because each represents the wood tissue produced by the cambium in one vegetative period, and a vegetative period is generally one year. By counting the annual rings the age of a tree can be determined; by considering their relative size in the same tree some idea of the conditions of growth at different stages can be formed: thick rings indicate favourable conditions, thin rings the reverse.

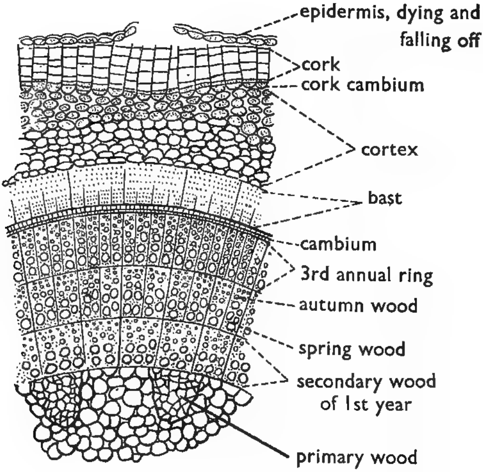


FIG. 8. Part of a transverse section of a three-year-old internode of a dicotyledonous stem

In transverse sections of the stem distinct light-coloured radial bands may be seen. These are known as *medullary rays,* and consist of certain cells formed from the cambium ring. The rays are of variable width, sometimes being only one cell thick, while in the oak and many other timber trees they may be several cells in thickness. They conduct, horizontally, water and various food substances manufactured in the leaves. In winter, starch and other food substances are stored in them for use the following season.

In stems of old trees the wood in the centre is heavier, harder, darker in colour, and drier than the outer younger wood. The dark wood is known as *heart wood,* while the outer softer portion is called *sap wood.* The heart wood acts as a strong support for the rest of the plant. Its cells have lost their contents and no longer conduct water, but usually contain gums, resins, tannin, and other substances, some of which provide stores of food and some of which act as preservatives against the attacks of fungi, thus making the heart wood more durable.

In the sap wood many of the cells are still living, and contain starch, sugar, and other compounds which, being liable to fungoid attack, decay easily and make the sap wood of less value as timber.

HEALING OF WOUNDS

When the mature wood of stem or branch is exposed, the wound soon becomes healed over (Fig. 9). The exposed cambium and the very young cells on both sides of it at once give rise to a soft mass of tissue termed *callus.* On the surface of the callus a corky tissue soon develops, while within, there develops a cambium which produces wood and bast. Gradually the new tissues produced by the cambium extend further and further across the exposed surface of wood until the edges meet all round. The development of callus is desirable, in that it provides a protection similar to that given by bark against fungoid attacks which cause decay. Clean-cut wounds heal more quickly than jagged ones, and so it is advisable to smooth off exposed edges of wounds. Again, when a branch is removed, as in pruning, it is necessary to cut back close to a bud or to a main stem to avoid a dead stub of wood which will remain long uncovered with callus and provide a means of entrance to agents of decay. When the exposed surface of wood is considerable it should be covered with paint or other proofing to keep out spores of fungi and bacteria which, with abundant water and air, would cause the tissues to rot.

Basal portions of branches become buried by the wood annually added to the stem. This is the origin of *knots,* which are hard due largely to the pressure of the surrounding wood. Knots may be avoided to some extent by planting trees for timber closely, so that lack of light prevents the growth of branches. Often, particularly in herbaceous plants, the exact central portion of the stem is occupied not by wood but by much softer material, which forms the pith.

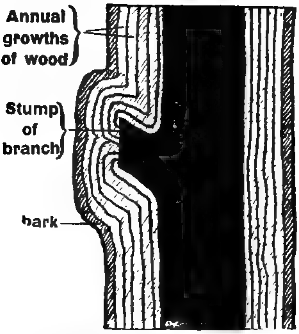


FIG. 9. Healing of wounds by callusing

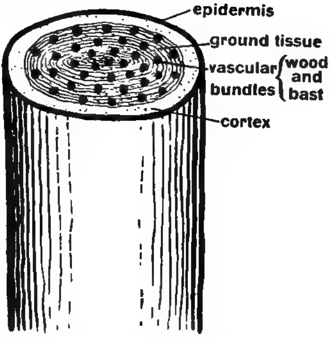


FIG. 10. Stem of monocotyledon

Stems of Monocotyledons (Fig. 10), e.g. lily and maize, differ in important respects from those of dicotyledons described above. There is a covering of colourless epidermis which may often be peeled off, then the cortex, which contains the green colouring matter as in the dicotyledonous stem, but there is no further resemblance. The vascular tissue (wood and bast), instead of being arranged in concentric rings, is scattered in isolated strands and embedded in a mass of ground tissue, which is sometimes similar to the pith of dicotyledons, but often again it is hard, and forms a firm tube, e.g., cereals. *There is no cambium present,* and so formation of new cells is impossible. Consequently, once the cells present have reached the full size there is no further growth in thickness of the stem such as occurs in dicotyledons by the formation of 'annual' rings. The stem of the cabbage tree (*Cordyline*) is an exception.

Exercise 1.—Cut a carrot root crosswise and lengthwise; examine the parts with the help of a magnifying glass; draw what you see. Separate the core from the rest and explain why the separation is easy and what you see arising from the core.

Exercise 2.—Cut twigs of a perennial woody plant, e.g., peach, apple, privet. Peel off the corky bark, then note that the soft bark consists of an outer green tissue (cortex), and a thin zone of colourless tissue (bast), which is separated from the central cylinder of wood by a moist, sticky, translucent, thin layer (cambium).

Exercise 3.—Examine under lens and microscope young stems and roots in transverse section and in longitudinal section, e.g. bean, mustard, fruit tree, grass.

Exercise 4.—Dip a twig which shows lenticels plainly, e.g., peach, into boiling water, and note what happens. Explain.

Exercise 5.—Examine logs or stumps, noting heart-wood and sap-wood, annual rings, rays, knots, resin ducts, corky bark, and soft bark.

Exercise 6.—Examine fruit trees or shelter trees to find instances of callusing where surfaces have been exposed by pruning, or breaking of limbs.

In the fully grown part of most stems the leaves are separated by intervals from each other. The points on the stems to which leaves are attached are called *nodes;* the lengths of stem between these are *inter-nodes.* The angle between the leaf and the upper part of the stem is known as the *axil* of the leaf. In the axils of leaves are the buds, which ultimately grow into branches of the stem. Though most stems naturally grow above ground there are cases where the stems are underground, and in such cases the first hint that such structures are stems is often provided by the occurrence of buds and of more or less modified leaf structures.

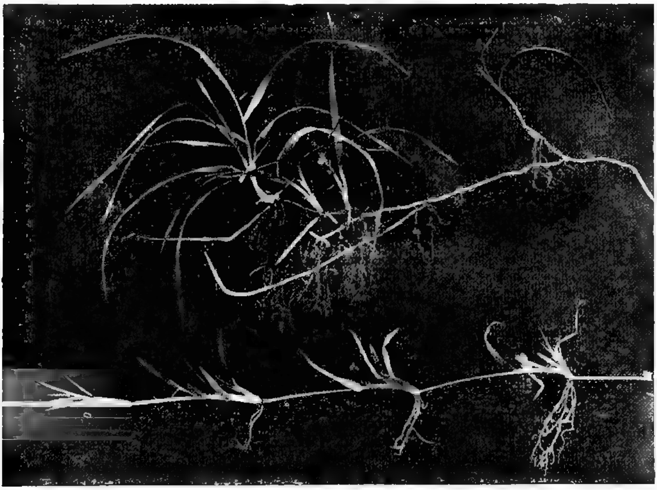


FIG. 11. Modifications of stems: The upper grass possesses a rhizome and the lower one a runner

FORMS OF STEMS

Stems which are comparatively soft when mature are termed *herbaceous.* They possess wood but only in thin strands and in small amount. Stems of practically all annuals, and also of many perennials, are of this type. Most stems of perennial plants, however, develop a considerable quantity of hard firm wood tissue, and are spoken of as *woody* stems. Trees and shrubs have well-marked woody stems. The typical stem grows straight up, as the erect habit usually allows the leaves to be borne so as to provide the maximum access of light and air. A number of plants have stems which are weak and incapable, of themselves, of growing erect. Many weak stems make their way upwards by attaching themselves to surrounding objects. The *climbing* is done by several different methods. *Twining* stems loop themselves around surrounding objects, e.g., hop, convolvulus, scarlet runner beans. *Tendrils,* which are wire-like coiling modifications of different organs, enable plants such as the vine and the pea to struggle upwards. The aerial roots of ivy, and the hooks of the blackberry are other instances of special climbing devices.

MODIFICATIONS OF STEMS

There are several modifications of shoots which receive special names. The main ones may be classified as follows:—

A. ABOVE GROUND

1. *Spines,* e.g., hawthorn, gorse. The fact that these hard, sharp structures arise in the axils of leaves and sometimes themselves bear leaves and side buds, indicates that they are modified shoots. Some gorse thorns are modified leaves (see page 80).

2. *Tendrils,* in some cases, are seen to be modified shoots by noting their position, e.g., vine and passion flower.

3. *Runners or Stolons* (Fig. 11) are stems which, extending horizontally over the surface, may or may not produce adventitious roots at the nodes. The buds on the stem grow into shoots and separate plants are formed by the decay or cutting of the internodes, e.g., strawberry, pennyroyal, and white clover, though occasionally the stem of the last is a rhizome (see Fig. 11). The term offset is applied to a stout runner rooting close to the parent plant, e.g., house leek.

4. *Cladodes* are branches which have taken on the appearance and general work of leaves, e.g., native brooms (*Carmichaelia*) and celery pines (*Phyllocladus*).

B. UNDERGROUND

5. *Rhizome* (Fig. 11), a horizontal stem, below the surface, which gives rise to aerial shoots and adventitious roots at the nodes, e.g., Californian thistle, yarrow, and twitches.

6. The *bulb* (Fig. 12) is a comparatively short stem upon which is placed a number of thick fleshy leaves, or, as in the case of the onion, fleshy leaf bases. At the apex of the stem is a growing point which, under suitable conditions, grows up into the air and produces leaves, using the food stored in the thickened leaves. At the same time adventitious roots are developed from the base of the stem, e.g., onion, lily, narcissus, hyacinth. The bulb may be regarded as a specialised underground bud.

7. The *corm* (Fig. 12) is a massive stem on which are a number of loose scale leaves sheathing the buds in their axils. In the spring these buds develop aerial shoots at the expense of the food stored in the stem, and adventitious roots form at the base of the bud, e.g., gladiolus, crocus. Corms are popularly referred to as bulbs.

Bulbs and corms are characteristic of plants exposed to the dangers of drought or of cold.

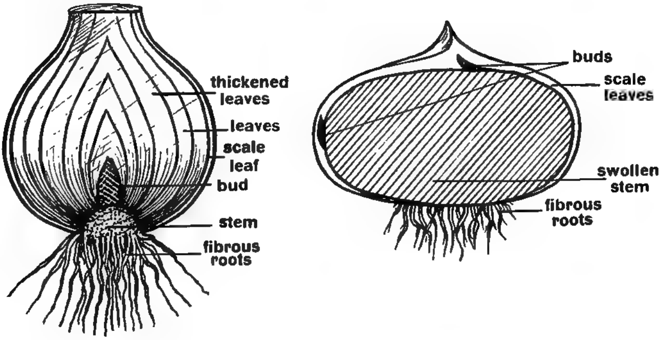


FIG. 12. Examples of a bulb (*left*) and a corm (*right*)

8. The *tuber* is a thick fleshy stem (Fig. 13) with a number of minute scaly leaves, in whose axils are buds or 'eyes', which, under proper conditions, develop into new plants at the expense of the food material stored in the stem. Tubers make their appearance either at the apex of a shoot or in the axils of scale leaves, and become swollen by the accumulation of reserve food material, e.g., potato, Jerusalem artichoke. The difference between a swollen root and a swollen stem is shown in Fig. 13.

9. The *sucker* is a shoot which is given off below the level of the soil, and which growing upwards, develops adventitious roots and aerial shoots. The sucker may arise from stems, e.g., mint, or from roots, e.g., poplar. Suckers often develop very rapidly, and rob the parent of water and food so that, except when required for propagation, they should be destroyed.

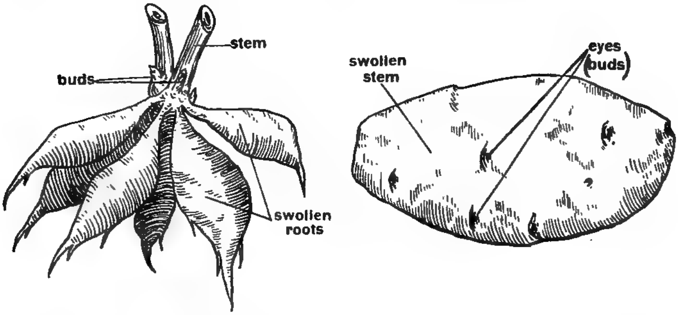


FIG. 13. *Left*: Tuberous root of dahlia. *Right*: Tuber of potato

BUDS

Buds may be defined as rudimentary shoots. From them arise the stems and leaves of all flowering plants. At the end of a stem or branch the internodes have not yet elongated, and the young leaves are crowded together and closely overlap the growing apex, forming what is called a *terminal* bud, which later develops into a further length of stem bearing leaves. It is important to notice that branches make their first appearance as buds, which are situated on the sides of the stem in the axils of the leaves. Such buds are termed lateral or *axillary*. Very frequently only some of these buds develop into branches. Those which remain quiescent are spoken of as *dormant* buds, and are chiefly near the base of the stems. Dormant buds lose their vigour with age, and many of them die without developing, but in some cases they are capable of activity for several years, and under certain conditions will give rise to what are called deferred shoots, which may give new life to a plant.

Injury or removal of the terminal and lateral buds at the top of the stem tends to stimulate the growth of deferred shoots from the dormant buds at its base. This explains why in sowing a cereal crop, e.g., wheat, that will be eaten down by stock at some stage and then allowed to mature, less seed is needed than for a crop not so eaten down. The injury to the first shoots stimulates dormant basal buds. The resulting formation of many shoots arising from near the surface of the soil which is called *tillering,* is common in members of the grass family. Plants receiving plenty of light tiller more than those grown in shaded positions, therefore thin sowing promotes tillering. Some plants tiller more than others, e.g., wheat more than oats, and the tillering of different varieties of the same species varies. The forcing of dormant buds is of importance in pruning operations, and also explains the 'pinching' of terminal buds in herbaceous plants to produce a bushy plant by the development of branches from the lower lateral buds. Bending of shoots, by checking the flow of sap to the higher buds, also promotes the growth of lower dormant buds. Buds may arise not necessarily in the axil of a leaf, but on any part, on stem, root, or leaves. Such buds are described as *adventitious.* Examples occur on the roots of docks, poplars, and bouvardias, on the injured stems of willows, various fruit trees, and gums (Eucalyptus).

In general, the largest buds are nearest the tips of shoots, and it is reasonable to conclude that these are the ones which will develop, being where light and space are most abundant, while the smaller lower ones remain resting, and serve as a reserve. Generally only one bud is produced in a leaf axil, but sometimes two or more occur, e.g., walnut, ash, peach.

The *structure of a bud* (Fig. 14) is best examined in the winter. In many cases the young leaves are all of the same kind, and ultimately develop into green foliage leaves, but frequently, especially in deciduous plants, only the central leaves of a bud are of this kind; the outer ones are small and scaly, and serve as a protection against cold and loss of moisture. Usually these scale leaves are specially fitted for their protective work, sometimes by a corky layer, sometimes by the secretion

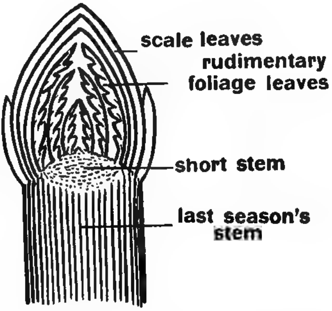


FIG. 14. Structure of a winter bud

of resin as waterproofing devices, and sometimes by the development of wool to temper abrupt changes in temperature. A section through a typical winter bud shows scaly outer leaves within which are ordinary foliage leaves arranged on a very short stem. In the spring the stem elongates and pushes out the foliage leaves from between the scaly leaves. The latter ultimately fall off, leaving small scars where they were attached to the twig. As these scars are often visible upon the bark for several years they are useful aids in fixing the age of any particular

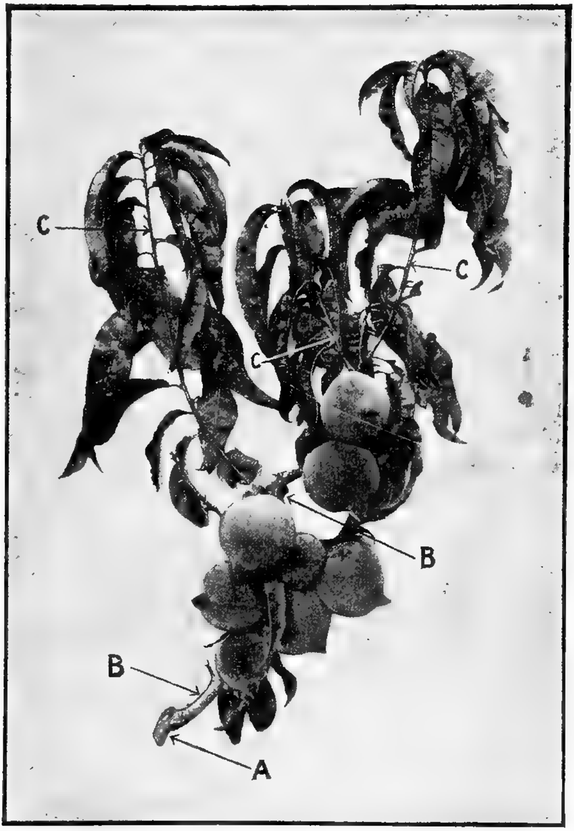


FIG. 15. Bearing habit of the peach. A: Two-year-old wood. B: One-year-old wood bearing the fruit. C: Current season's growth

(*Hawkesbury Agric. College*)

length of stem or twig, the amount of growth in any one growing season being indicated by the distance between the two sets of scars.

Wood Buds and Fruit Buds

Buds which develop into green foliage leaves and produce new woody twigs are named wood buds.

Many buds give rise to flowers which may or may not be accompanied with green leaves. These are called fruit buds, because it is from them that fruit will be obtained if the flower is pollinated and fertilised. (See Chapter 7).

For pruning and other operations it is desirable to be able to distinguish between wood and fruit buds in the dormant season. Though no hard and fast rules can be laid down, as exceptions occur due to manuring, season, and management, yet the appearance and position of buds gives considerable guidance

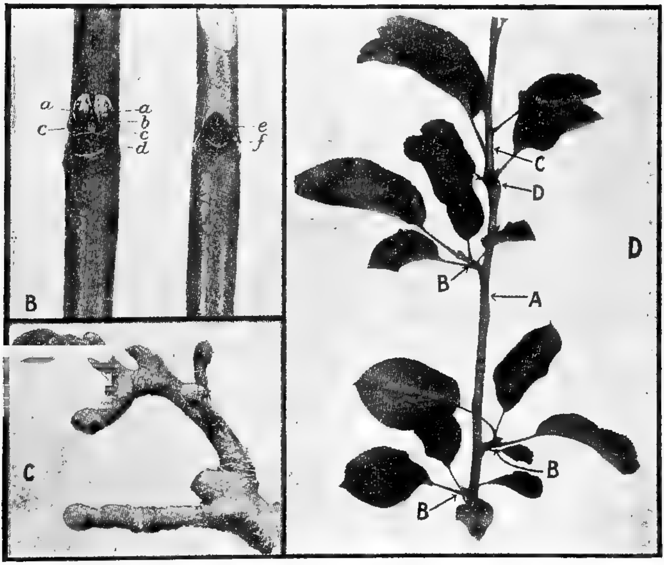


Fig. 16. Peach wood: B *aa* Fruit buds; *b* Wood bud; *d* Butt of last year's leaf; *e* Wood bud; *f* Butt of last year's leaf
C Fruit spur of apple
D Apple twig: A Last season's wood; B First stage in the formation of fruit spurs; C Current season's growth; D Point of previous winter pruning

(*From Allen's 'Pruning'*)

as to their nature. In apples and pears the wood buds are small and pointed; the fruit buds are larger and plumper, and are usually developed on short lateral twigs called 'spurs', which are produced on wood two or more seasons old, whereas usually wood buds alone are found on long shoots only one year old. In some varieties, however, the fruit buds are borne largely on shoots of the previous season's growth, e.g., Jonathan, Irish Peach, Cox's Orange Pippin, and Delicious, which are spoken of as 'tip bearers', in distinction from the 'spur bearers'.

In the peach (Fig. 15) and nectarine the fruit buds are borne on one-year-old shoots, and blossom the year after they are formed.

The apricot bears the fruit buds on one-year-old shoots, and also on spurs, but chiefly on the former.

The gooseberry and black currant resemble the apricot.

The rose, the grape vine, and the passion vine are examples of plants which produce flowers and fruit on the current season's growth.

The plum bears chiefly on spurs, but sometimes on young long shoots.

The quince, in spring, develops leafy shoots from dormant buds on one-year-old twigs, and each of these shoots terminates in a flower. The most vigorous flowers are produced not from terminal buds but from side buds.

READING

Agricultural Botany,
Yeates and Campbell

N.Z. Journal of Agriculture,
(Seasonal notes and articles)

4

How Plants Get Water and Minerals

LIKE ALL living things plants build their bodies out of substances classified as carbohydrates, fats, proteins, water and minerals. In contrast to animals, however, green plants are able to make their own food from simple substances taken out of the atmosphere and the soil. For this building and for their other living processes they need special substances called enzymes or organic catalysts which help the chemical changes involved. As all of these substances are composed of chemical elements, it is convenient to think of the needs of plants in terms of the elements.

First there are the elements needed in large amounts to make the plant tissues themselves, viz., carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur. Second are those needed in small amounts chiefly in helping to make enzymes and in regulating the life of plants, viz., potassium, calcium, iron and magnesium and sometimes sodium. Third are those needed in minute amounts, the trace elements, viz., boron, copper, manganese, molybdenum and zinc.

Some elements are found in fairly large amounts in plants but whether or not these elements, viz, silicon, aluminium and chlorine, are actually needed is not known. Then there are some elements which may or may not be required in traces, e.g., vanadium and tungsten.

The needs of animals for trace elements seem to be somewhat different from plant needs. Sheep and cattle must have cobalt and all animals iodine, both of which elements are not apparently required by plants. On the other hand plants must have boron which animals do not require. (See page 221.)

All the carbon required by an ordinary green plant comes from the carbon dioxide of the air, which is absorbed by the green parts of the plant, while the other elements are absorbed by the roots.

Water is present even in air-dry plants; it may be driven off by drying the plants in a water oven avoiding charring them. In woody parts the percentage of water is about 50; in herbaceous parts about 75, and in fleshy parts (fruits) from 85 to 95.

The remaining dry material, which gives the dry weight, consists of:—

(a) *Combustible* matter, which is made up of carbon, hydrogen, oxygen, nitrogen, and which disappears into the air when the plant is burnt. The carbon is often as much as one half the total dry weight.

(b) *Incombustible* matter, which represents the mineral substances, and which remains as ash. The amount of ash varies in different plants, in different parts of the same plant, and increases with age.

PLANT ANALYSIS

All the elements present in plants have been discovered by plant analysis. The presence of some of these elements can be shown by simple experiments such as those following.

COMPOSITION OF PLANTS

Exercise 1.—To find the dry weight of plants weigh pieces of carrot, turnip, mangel, potato, apple, etc., in separate crucibles. Then cut each piece into several small pieces, and place the porcelain dishes and contents into a warm oven, or 'water oven'. Weigh them at intervals till they show no further loss in weight, thus showing that all the moisture has been driven off. In this way the percentage of water and of dried substance is obtained after allowing for the weight of the crucible.

grammes.

Line 1—Weight of crucible =

Line 2—Weight of crucible and carrot (before drying) =

Line 3—Weight of carrot before drying = line 2–line 1

Line 4—Weight of crucible and carrot (after drying) =

Line 5—Loss in weight (moisture) = line 2–line 4

$$\therefore \text{Percentage of moisture} = \frac{\text{line } 5}{\text{line } 3} \text{ of } 100$$

Repeat the above experiment with fresh leaves of turnip, rape, grass, oats, maize, lucerne.

Exercise 2.—To show the presence of carbon. Taking some of the dry matter from the previous experiment mix it with dry black copper oxide in equal amounts in the test-tube. Fit a tube to the test-tube, lead it into lime-water in another test-tube and heat the mixure. What happens? Explain the action. Why was copper oxide used?

Exercise 3.—To show the presence of hydrogen and oxygen in a dried plant. Heat another lot of dry matter of a plant in a test-tube. Hold a flask of cold water (dry on outside) near the mouth of the tube and note the condensation on the flask. Add a little anhydrous copper sulphate powder to the condensed liquid, which, if it is water, will turn the powder blue. What do you conclude?

Exercise 4.—To show the presence of nitrogen heat a further lot of dry plant material mixed with about half its volume of soda-lime in a test-tube. Smell the gas given off and test with litmus paper. Record what you observed, and, realising the gas is ammonia, what do you conclude?

Exercise 5.—To find the amount of ash in plants dry and weigh porcelain crucibles, and place in them the oven-dried material from the previous experiments, and heat thoroughly. The material chars and flame may appear. In 10 minutes or so the dry material is reduced to a fine ash. Cool and weigh at intervals till no further loss occurs. Record the result in a similar way to finding the dry weight of plants.

THE ROOT

Roots generally grow downwards into the soil, bear no leaves, and give rise to many branches, some of which are very fine, and hence capable of exploring the minute soil spaces. There are several kinds of roots.

(1) In many dicotyledons the radicle extends and forms the *primary* root, which bores deeply into the soil in a downward direction. Branches growing horizontally arise from the primary root and subdivide again and again, forming an extensive collection of roots, which is called the *Root System,* and which is of value in that it explores the soil space as much as possible.

(2) The majority of the lateral branches will be found, on careful examination, to be arranged in rows along the primary root, and not in irregular order as at first sight seems to be the case. They first appear near the cotyledons, and are followed by others nearer the tip: hence the relative age of the branches is indicated by their position on the primary root. Root branches thus arranged in *regular* order are called *secondary* roots, and by further branching they in turn give rise to *tertiary* roots. Five rows of secondary roots occur in the bean, two rows in mangel, three rows in red clover, and four rows in carrot. Secondary roots do not arise as outgrowths from the surface of the primary root, but come from within it.

(3) When the primary root remains distinctly larger than the lateral ones it is called a *tap root,* e.g., rib-grass, dandelion, dock. In many cases, particularly with biennial plants such as the

carrot and mangel, the tap root is swollen and fleshy, and serves to store food for future use. Swollen irregular roots, e.g., dahlia, are known as tuberous roots (Fig.), and must be distinguished from tubers, which possess buds ('eyes') that do not occur in tuberous roots. When the primary root remains slender and becomes rivalled in size by its branches we have *fibrous* roots, e.g., grasses.

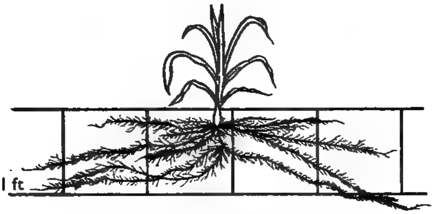


FIG. 17. Dent maize, 36 days old

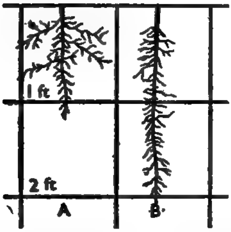


FIG. 18. Sugar beets about two months' old: A, dry land with practically no water available in the second foot; B, irrigated soil

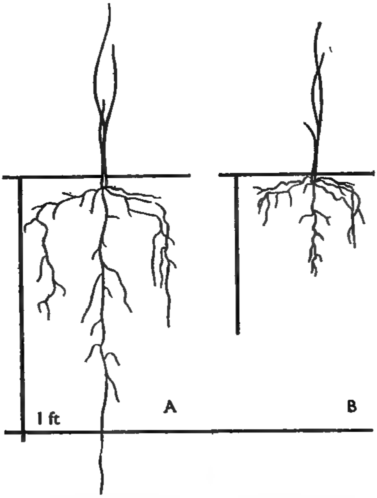


FIG. 19. Onion seedlings of the same age: Plant B was grown in compact soil, A in loose soil. Both drawings to the same scale PLANT ROOT SYSTEMS (*After Weaver and Clements in 'Plant Ecology'*)

(4) Roots which appear on stems or leaves and roots which arise on other roots but not in regular succession are described as *adventitious* roots (Fig. 12). They are well exemplified in grasses and cereals, in which the roots that develop from the seed are merely temporary, and are superseded by roots which grow out from the lower nodes or knots of the stem near the surface of the soil. Adventitious roots are also met with on the creeping stems of white clover and strawberries, on the underground stems of twitches, Californian thistle, and mint. Their formation is made use of in the propagation of plants by runners, cuttings, and layers.

Exercise 6.—Germinate broad bean seeds on damp flannel, or in sawdust. Watch the development of primary and of secondary roots. Note the rows of the latter. By slicing along the rows note that the secondary roots arise from within the primary root.

Exercise 7.—Carefully dig up and wash the soil from carrot, mangel, turnip, radish. How many rows of secondary roots can be distinguished? Split off the rind of the carrot and find whence the secondary roots arise.

Exercise 8.—Sow barley, wheat, and oat grains 2 to 3 inches deep in moist sand or loose soil, and when the seedlings are about 3 inches above the ground carefully remove and note (a) the roots which developed from the grain, and (b) the secondary roots arising from the node on the stem. The former are called 'seminal' roots. What are the latter called?

Exercise 9.—Examine the roots upon any cuttings or layers available, and observe whether they arise at the cut surface or at some distance away from it. What kind of roots are they?

Exercise 10.—Examine the roots on sorrel, Californian thistle, Poa pratensis, couch, pennyroyal, doobj grass, strawberry. Which of these plants have underground stems?

Exercise 11.—Make as complete a study as possible of the extent and situation of the root system of well-grown maize, potato, mangel, ryegrass, red clover, and lucerne plants. Where is the greatest portion of the root system found? How far do the roots extend in a lateral direction? What is the special feature about the roots of lucerne?

All the chief farm plants should be similarly examined, the main points to note being the presence or absence of tap root, the amount of branching, the horizontal extension, and the depth to which they descend. (See Figs. 17, 18, 19.)

The *root systems* of plants vary greatly, but as a general rule much of the development is restricted to the topmost layer of the soil which has received cultivation. Hence, to encourage a deep root growth, it is usually necessary to cultivate deeply. Further, in the top few inches of soil, the roots will be found to extend laterally to considerable distances. Hence to avoid injury to the root system of growing crops only shallow cultivation between the rows is permissible.

The root system of some plants is naturally deep, of others shallow, a point which partly determines the soil or the place in the rotation to which any crop is adapted. Wheat roots penetrate more deeply than those of barley and maize; mangels and carrots more than cabbage and turnip. Pear, apple, and cherry penetrate more deeply than peaches and lemons. Knowledge of such facts teaches that if barley follows wheat different regions of the soil layer will be drawn on for food material, that carrots require a deeply cultivated soil, and so on.

Sandy and open soils stimulate a large and deep root system, whereas in water-logged soil the roots of farm crops are restricted to the surface layer.

Injury to roots stimulates the formation of root branches behind the mutilated part. This explains the 'wrenching' carried out in nurseries. Many plants are moved in the rows so that the tap root, which becomes broken, develops a ball of fibrous root branches above the break in place of the single descending tap root.

Certain soil fungi, known as mycorrhizas, work in an obscure but beneficial way with many plant species, e.g., *Pinus*.

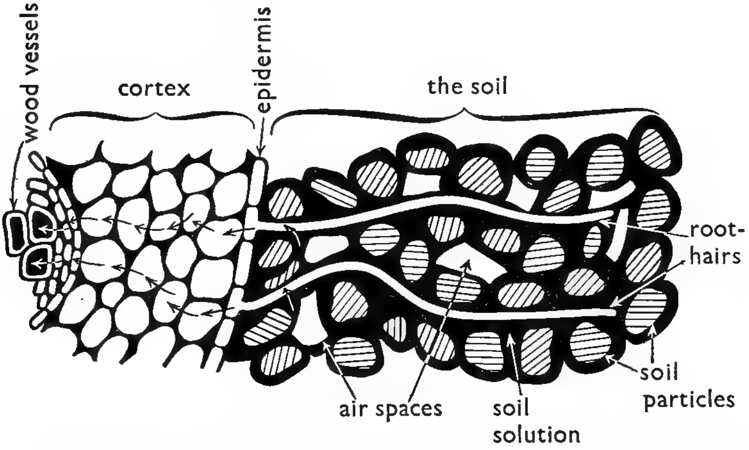


FIG. 20. Diagram of root hairs in soil, showing path of water movement from soil into wood conducting tubes

5. *Root hairs* (Fig. 20) must be distinguished from tiny rootlets, with which they are often confused. Root hairs are seldom seen on a plant which has been removed from the soil, for they are so delicate that they become broken off in lifting. They are thin-walled tube-like structures and may be observed as white silky bands on the roots of seedlings germinated on moist flannel or absorbent paper. They are developed a short distance behind the point of the root, and disappear from the older parts. They come into very close contact with the particles of soil, and with the film of moisture surrounding these particles. The surface of the root is multiplied many times by these root hairs, which

are really outgrowths of the epidermal layer. They are of extreme importance because food material obtained from the soil is taken in by them. They are most abundant in moderately moist soil, and their number is often increased by a good supply of lime. Plants growing in very wet situations have few or no root hairs, while in dry soils their development is also checked.

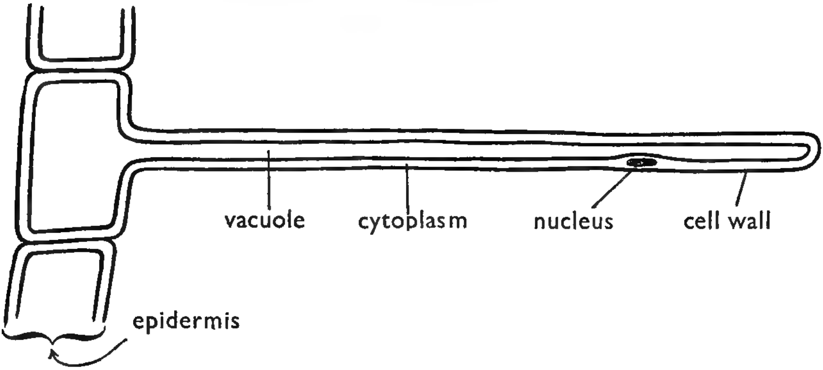


FIG. 21. Diagram of a root hair

ROOT HAIRS

Exercise 12.—Germinate beans, mustard, barley, oats and red clover on moist, black cloth, and examine the root hairs on the primary roots, and note their delicate structure, and their abundance.

Exercise 13.—Sow seeds in sand, and, when the seedlings are about to produce their first foliage leaves, remove the seedlings carefully from the soil and place on white paper. Note where the sand adheres to the roots. Explain.

Exercise 14.—Under the growing tip of a root place gelatine tinted with litmus or moist blue litmus paper so that the root will travel across it. Watch for the appearance of a red band just under the root. What does this indicate?

Exercise 15.—Taking a portion of a root of a seedling with root hairs place it in a cavity microscope slide and examine the root hairs under a microscope. Try to identify the parts as indicated in the above diagram.

HOW ROOTS TAKE IN WATER

Water and mineral salts are absorbed from the soil by root hairs which are special epidermal cells occurring in young roots. Neither the absorption of water nor the absorption of minerals is a simple process and each process goes on independently of the other.

Some idea of what goes on during the absorption of water from the soil can be gained from simple experiments.

TO SHOW OSMOSIS

Exercise 16.—Chip an area, about the size of a shilling, of the shell off the bottom of an egg, taking care not to break the delicate inner membrane or skin. Open the top and remove the contents, and place inside a few spoonfuls of strong sugar solution (preferably grape sugar or glucose). Stand the egg as shown in Fig. 22 with the exposed membrane dipping into a weak bluestone solution. The volume of liquid inside the egg will considerably increase, and a bluish tinge will appear, showing that bluestone has passed in through the membrane. By testing, the solution outside will be found to contain some sugar.

Set up a duplicate, using, however, carmine or starch in the liquid outside the egg. By testing the contents of the egg it will be found that these materials do not pass inwards—they are not dissolved.

The two experiments show:—

1. That water passes inwards—indicated by the increased volume.

2. That there is a movement of material both inwards and outwards.

3. That the greater movement is towards the stronger solution.

4. That dissolved substances pass through the membrane, but that insoluble ones do not.

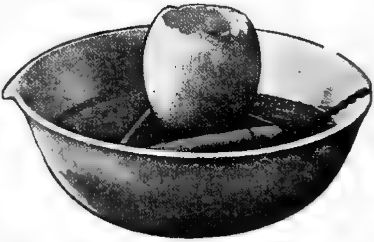


FIG. 22. Egg shell set up to demonstrate osmosis

Exercise 17.—Set up the following apparatus to represent a simple model of a root hair: Firmly tie a cap of cellophane over the mouth of a thistle funnel. To ensure air-tight joint apply marine glue to cover the junction. Fill the thistle and an inch or two of the tube with strong sugar solution and stand it with the covered end dipping into water.

An effective way of getting a tight joint in this root hair model is to use a hose connection instead of a thistle funnel. Unscrew the cap of the hose connection, place cellophane over the wider opening and screw on the cap. Fill the connection with a strong solution of sugar, join the narrower end to one or more lengths of capillary tubing and hold it up by stand and clamp with the hose connection and contents immersed completely in a beaker of water. It is desirable to have the narrower end of the hose connection reduced in diameter to coincide with the diameter of the capillary tubing by welding on a suitable narrow tube.

Make a drawing of the apparatus, labelling the parts and giving in brackets after each label the corresponding part in a root hair. Observe the rise of water in the tube, the rise corresponding to the increase in volume of the liquid in the vacuole of a root hair and the passage of water into the root. This rise continues until a state of balance is reached.

AN EXPLANATION OF OSMOSIS:

There is a tendency throughout nature towards achieving a state of balance where for some reason or other a state of unbalance exists, e.g., water tends to find its own level, a hot body in a cool atmosphere cools down and the atmosphere warms up until the body and the atmosphere reach the same temperature. In the case of the model of a root hair, just set up, we also have an unbalanced system due to the sugar solution being separated from the water by the cellophane membrane which allows water molecules to pass through it but not sugar molecules. A membrane like this is called semi-permeable and the molecules of the water and the sugar around it are in a state of perpetual motion, bombarding it. The tendency is for the concentration of the water inside and outside the membrane to become uniform or balanced. As the concentration of the water is greater outside the tube than inside it, more water tends to move or diffuse to the inside than to the outside. This greater movement of water inwards through the semi-permeable membrane is called *osmosis*. As a result, the liquid rises in the tube and produces pressure downwards due to its height and weight. The rise of liquid continues until a balance is reached when the pressure in the tube forces water out through the membrane at the same rate as the diffusing force causes water to pass inwards. The height of the liquid in the tube is a measure of the *osmotic pressure* which is the extra pressure which must be applied to a solution to prevent osmosis taking place.

Let us now see how this experiment is related to a root hair. In a root hair there is the outer cellulose cell-wall which is completely permeable to the soil solution, the name given to water containing dissolved mineral salts in the soil. Inside the cell-wall is a layer of cytoplasm which is semi-permeable, that is permeable to water but not to solutes, and right inside the root hair is the vacuole containing cell-sap, a solution of sugars, other organic substances and inorganic or mineral substances.

Cell-sap has a much higher concentration of solute molecules than soil solution. Passing straight through the cell-wall the soil solution reaches the layer of semi-permeable cytoplasm. So a root hair in soil has a concentrated solution, the cell-sap, separated from a weak solution, the soil solution, by cytoplasm which is a semi-permeable membrane. Water molecules can pass across the membrane both inwards and outwards, but more water enters the cell than leaves it, i.e., the root hair absorbs water from the soil. As this absorption continues, the root hair cell becomes swollen, and the protoplasmic lining presses tightly against the cell-wall and makes it rigid. The further osmosis proceeds the more rigid the cell becomes and the rate of osmosis becomes lower.

Osmosis occurs not only in root hairs but also throughout the active living cells of plants, so that water passes from one cell to another giving nourishment and promoting rigidity. Cells which are made rigid by water absorption are said to be *turgid*. Osmosis between cells in a root and shoot causes a demand for water from the root hairs so that osmosis proceeds as long as water is available in the soil.

TO SEE HOW WATER PASSES FROM CELL TO CELL BY OSMOSIS

Exercise 18.—Taking a long potato tuber, cut off the end of the tuber so that it will stand upright, and from the other end scoop out the interior leaving an outside layer about one-quarter inch thick. Half fill the cavity with a strong solution of salt or sugar coloured with red ink, and stand it in a dish of water the level of which is not above that of the solution in the tuber. From day to day watch what happens and explain.

Proceed similarly with another potato tuber, cooked instead of living (raw). Is there any difference between the two experiments? Explain.

During dry weather it is common to see plants wilting. Such plants have lost more water from their cells, chiefly by evaporation from their leaves, than they have gained from the soil solution by osmosis. Their cells have insufficient water to keep them rigid, i.e., the cells have lost turgor.

Exercise 19.—Observe pumpkin and marrow plants during a hot summer's day.

A similar situation occurs soon after transplanting. When a seedling, such as lettuce and cabbage, is dug up for transplanting many of its root hairs are damaged. Hence, when it is replanted in its permanent position, it has few root hairs to absorb water from the soil, so it wilts until new root hairs have developed.

If soluble fertilisers are applied heavily to soils, the concentration of the soil solution may become close to or exceed that of the cell-sap of the root hairs of plants growing in those soils. Instead of water being absorbed by the root hairs, water will be lost from the plants, their cells will lose turgor and they will wilt.

TO SHOW HOW THE OSMOTIC ACTION OF PLANTS IS AFFECTED BY THE STRENGTH OF THE SOLUTION

Exercise 20.—Take three flasks or large test-tubes (Fig. 23). Fill one with water, another with sodium nitrate solution, at the rate of 2 grammes of sodium nitrate to 100 c.cm. of water, and the other with sodium nitrate solution, at the rate of 25 grammes to 100 ml. of water. Into each place the roots of a fresh young plant, and watch the effect at intervals for a period of a few days. Cabbage, lettuce, mallow and milkweed (*Euphorbia*) are suitable plants for this experiment.

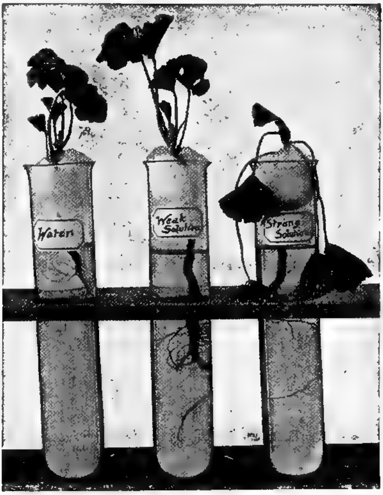


FIG. 23 Experiment to show how the osmotic action of plants is affected by the strength of the solution

This is what happens when dressings of salt are used to kill weeds; it may also happen when soluble manures, particularly nitrate of soda or sulphate of ammonia, are used in excess.

The osmotic absorption by root hairs goes on only when there is an adequate supply of warmth and of fresh air. At low temperatures absorption greatly decreases or ceases altogether, even though the roots have access to plenty of water. Though the loss of water from the leaves falls off, a low temperature does not cause it to cease. Hence we get the so-called 'burning' by frost when leaves lose water which is not counterbalanced by root absorption. Anything, such as a covering of snow, which checks the escape of water from the leaves, lessens the danger of 'burning'.

The temperature of imperfectly-drained soils is usually lower than that at which farm crops are able to absorb most rapidly, and hence the rate of growth which depends on the rate of absorption is decreased. Pot plants often suffer through the use of water so cold as to check absorption; also through an excessive supply of water excluding air and thereby lessening the rate of absorption.

After water has entered a root hair and passed from cell to cell by osmosis, it enters the wood (see Fig. 20), and travels in the wood vessels up the root and the stem to the leaves.

To Find the Region of Transport of Water in Plants

Exercise 21.—Take two fresh young plants such as broad beans or lettuce. Set one with its roots immersed in water coloured with red ink (soluble). Set the other with the roots dipping into water coloured with carmine (insoluble). After a few hours observe whether the coloured matter has travelled up through the plants in each case by cutting the stems across and looking at the cut ends under a magnifying glass. Draw what you see. In which part of the stem does water travel upwards? What other conclusion can you make?

HOW A PLANT GETS MINERALS

As we have seen in studying osmosis, the soil solution is usually a dilute solution of minerals in water. In a fertile soil this solution, in the form of films of liquid surrounding the soil particles (Figs. 20 and 57) contains all the elements necessary for proper plant growth. The clay and the humus of the soil are mainly responsible for holding the minerals preventing them being washed away in the drainage water. (See page 182.)

Exercise 22.—To show that soluble salts are present in soil. Taking about 200 gm. of soil shake it up in about 100 ml. of water. Decant and filter the liquid. Evaporate the filtrate to dryness in an evaporating dish on a beaker of boiling water. Is anything left in the dish? What do you conclude?

Little is known about the way a root hair absorbs mineral salts from the soil. It is known, however, that it is a process independent of osmosis, the way water is absorbed. As the minerals must move from a region of low concentration, the soil solution, to a region of high concentration (the root hair cell sap, i.e., moving as it were uphill), the process must need much energy. This energy is obtained from the respiration of the root hair, mainly the oxidation of sugar in the cell sap. Now respiration or breathing is a living process requiring both an adequate supply of fresh air with its oxygen and sufficient heat and is most active in young cells. Hence for mineral absorption, roots must be in soil that is well aerated, that has a temperature above a certain level, depending on the plant, and the roots must be renewing themselves continually.

If the soil is poorly aerated, not only will mineral absorption by the root hairs be slowed up but there may even be movement of minerals out of the root hairs back into the soil. That there is probably always some transfer of minerals from the root to the soil even when soil conditions are at their best for plant growth is shown by experiments with radio-active tracer elements. It seems that transfer of minerals between soil and plant is to some extent a two-way process.

We have seen that root hairs can absorb only dissolved substances. Many of the mineral substances required by plants generally exist in the soil in a form insoluble in water, but become soluble in the soil water. This dissolving action of the soil water is due mainly to the carbon dioxide given off by plant roots in their respiration, the carbon dioxide forming carbonic acid with the soil water, and to the humic acid from decomposing organic matter. In addition, there are probably other acids excreted by the root hairs which help in dissolving minerals making them become available to plants, e.g., 'some species of lupins apparently excrete acids that can bring relatively insoluble phosphate into solution', (Russell's *Soil Conditions and Plant Growth,* p. 484).

Tricalcic phosphate, the valuable ingredient in rock phosphate, and calcium carbonate are substances affected in this way.

SELECTIVE POWER OF ROOTS

The amount of any particular substance taken from the soil by a plant does not depend wholly on the amount of the substance in the soil, for different plants have different needs, and take their food elements in different proportions from the soil, e.g., cereals take less than half as much nitrogen, lime, and potash as root crops (turnip, mangel, potato). This partly explains the fact, well known to farmers, than on most soils it is better to change the kind of crop grown from year to year.

CULTURES

To determine with certainty which elements are necessary for proper plant nutrition, and to discover what part each element plays in plant development, experiments must be carried out in material the composition of which is known accurately. This is best done by methods of water culture or sand culture which consists of growing plants in distilled water or washed sand to which are added compounds of the elements whose influence is to be studied.

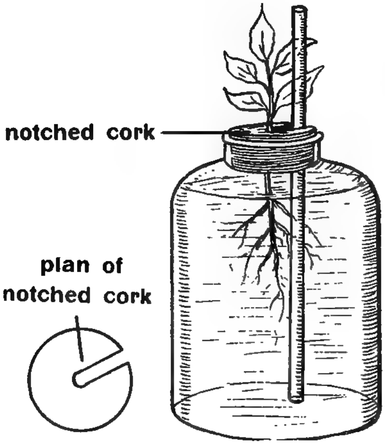


FIG. 24. Bottle arranged for water culture. (See Exercise 23)

In the chapter on fertilisers mention is made of the functions of the three elements *phosphorus*, *potassium*, and *nitrogen*, which are of particular importance because the available supply of them is frequently deficient in soils. The following is a brief account of the other essential elements.

1. *Carbon,* which is obtained from the air, enters into the composition of protoplasm, of cell walls, and of many reserve foods.

2. *Hydrogen* and *oxygen* occur combined with carbon and other elements in protoplasm, cell-wall, sugars, fats, etc. Hydrogen is a constituent of water, and is absorbed from the soil in this form. Oxygen is absorbed from the air, and also from the soil combined with various minerals.

3. *Calcium,* which is absorbed from the soil, is essential for green plants. Though it may be missing altogether in young parts, yet plants cannot reach maturity without a normal supply.

Some, like clovers, peas, and lucerne, require so much for their development that they are called 'lime' plants. Calcium appears to take a prominent part in the production of new tissue. It also stimulates root production, and assists in imparting vigour and hardiness to crops. It is assimilated in the early stages of growth, e.g., in wheat 80 per cent is assimilated before the heads appear. Prominent as calcium pectate in the middle layer of cell walls, it tends to accumulate in leaves. A good calcium supply helps to overcome the effects of unbalanced distribution of soil nutrients. A soil can, however, be too rich in calcium, one prominent effect of this being that such a soil may require heavy applications of potassic fertilisers.

4. *Sulphur,* which is absorbed from the soil, enters into the composition of proteins, and of the 'oil' which is obtained from many crucifers. Sulphur applied as manure has been found to be useful for heavy crops rich in protein.

5. *Magnesium* occurs in chlorophyll, a fact which accounts for the lack of green colouring in magnesium-starved plants. It also seems to be necessary for the formation of oils. When plants are grown with an incomplete supply of magnesium the seeds are frequently sterile. Deficiency of magnesium is observed not so much in the first stages of growth as near the time of seed formation, when its absence is followed by checked development.

6. *Iron* is absolutely essential for the formation of chlorophyll, and when plants fail to obtain their normal supply of iron they do not develop their normal green colour.

7. *Sodium,* though not an essential food material, is of importance in that it can partially replace potassium. Hence sodium salts can be used with some effect as manures wherever there is a deficiency of potash in the soil.

WATER CULTURES

Exercise 23.—Nine wide-mouthed glass bottles holding about 500 ml. each are required. Clean the insides thoroughly by rinsing with nitric acid followed by plenty of rain water, and finally by distilled water. Paste black paper over the sides and necks of the bottles to exclude light, so that microscopic plants called algae cannot grow to clog the roots. Fill the bottles close to the top with distilled water. Then using 100 ml. of distilled water in each case make up the following solutions:—

(a) 1 gramme of sodium nitrate.
(b) 1 gramme of potassium chloride.

(c) 1 gramme of magnesium carbonate.

(d) 1 gramme of monosodium phosphate.

(e) Saturated solution of calcium sulphate.

(f) 1 gramme ferric chloride.

Number the bottles from 1 to 9.

To 1 add 5 ml. of each of the solutions labelled A to E, and a few drops from solution F. This supplies a *complete* plant food.

To 2 add as to 1, withholding solution A, and thereby supplying no *nitrogen*.

To 3 add as to 1, but withhold solution B—no *potassium,*

To 4 add as to 1, but withhold solution C—no *magnesium*.

To 5 add as to 1, but withhold solution D—no *phosphorus*.

To 6 add as to 1, but withhold solution B and E, and add 5ml. of potassium sulphate solution (1 gramme in 100 ml. distilled water)—no *calcium*.

To 7 add as to 1, but withhold solution F—no *iron*.

To 8 add as to 1, but instead of solution E use solution of calcium chloride (1 gramme in 100ml. distilled water) thus giving—no *sulphur*.

To 9 add nothing—*control*.

Select nine well-fitting corks, and cut notches in them as shown. Obtain nine glass tubes of sufficient length to reach from the bottom of the bottle to about a foot above the cork. Wash these thoroughly as directed for the bottles. By means of these tubes the solutions are aerated once daily to give oxygen for the breathing of the roots, and a support provided for the seedlings (Fig. 24).

Obtain nine plants with straight roots and as nearly equal as possible in all respects. (See note (d) below.) Barley, mustard, lettuce, and cabbage are among those suitable. Place a plant in the centre of each cork, and hold it in place with cotton wool or asbestos wool. Taking care not to damage the roots, fix the seedlings so that their roots dip into the solutions. Then attend to the following points:—

(a) Avoid wetting the cotton wool or asbestos wool so that fungus cannot grow to rot the stems.

(b) Add fresh distilled water to keep the bottles well filled, and add more of the nutritive solutions to plants which have developed considerably.

(c) Aerate the solution from time to time by gently forcing air down the glass tube with a bicycle pump, or by any other suitable means.

(d) The necessary seedlings may be obtained by sprouting them in blotting paper. Aldridge's method is very suitable. He recommends placing a row of seeds about an inch from one side of a sheet of blotting paper, which is then rolled up tightly enough to keep the seeds in place. The roll is then set in a cylinder, the seeds being at the top, and a little water is placed at the bottom of the cylinder. For larger seeds, moist sawdust is suitable for sprouting.

WORK OF ROOTS

The work of roots consists of:—

A. *General* functions performed by the great majority of roots of all plants—

1. Roots hold the plant firmly in the soil and by means of the innumerable root fibres explore the soil space and bring the delicate absorptive root hairs in close contact with the soil particles and soil moisture.

2. Roots are the means by which the plants receive their supplies of water and minerals—the raw materials from which part of their plant food is manufactured.

B. *Special* functions characteristic of only certain plants or classes of plants—

3. Roots store food. In biennials (i.e., plants which in the first year produce leaves and shoot and in the second flowers and fruit) reserve food is sometimes stored in thickened roots. The parsnip and kumara roots contain starch and sugar. The carrot, turnip, beet, and mangel contain sugar.

4. To the roots of clover, lucerne, peas, beans, vetches, lupins, lotus, medick, and other plants of the *legume family* are attached wart-like nodules (Fig. 65). These are colonies of minute plants known as bacteria, between which and the leguminous plants an interchange of mutual advantage takes place. (See page 187 for further information.)

Exercise 24.—Dig up leguminous plants, such as clover, lupins, peas, gorse, and observe the nodules.

5. Plant roots can affect other living things in the soil, e.g., beans and perhaps peas may excrete something into the soil that kills wireworms.

6. The desirable crumb or granular structure of soil is built up by the roots of many plants, especially grasses.

7. Strong growing roots can penetrate compact subsoil thereby improving drainage and aeration.

Exercise 25.—Carefully remove a grass plant with its roots from the soil. Note the large number of small soil crumbs and clusters of crumbs hanging on the roots.

READING

Agricultural Botany, Yeates and Campbell

**Soil Conditions and Plant Growth,*
Russell, E. J.

*The *School Science Review,*
Mar. 1951, p. 186, and Oct. 1945, p. 100

**Science News,* No. 25, Aug. 1952, p. 53

* Mainly useful to the teacher

FILMS

(The National Film Library)
'How Plants Feed'
'Plant Growth'

5

How Plants Get Energy

SEEDS, as we have seen in Chapter 2, have stores of food substances mainly carbohydrates, fats and proteins which, when the seeds germinate, are used for breathing, growth and other living processes of the seedlings. Because seedlings are living more vigorously than seeds, seedlings need more energy than seeds. Food substances such as those existing in seeds are stores of *energy,* energy which is needed by all living things both plant and animal.

Little is known about energy, but it is known that it takes various forms such as heat, light, electricity, sound, chemical energy and atomic energy, and that one form of energy can be turned into another. Thus, if stored chemical energy in the form of petrol is burned (oxidised) in a suitable place, like the cylinders of an engine, the chemical energy is turned into heat energy capable of producing movement and doing work. So man, other animals and plants turn stored chemical energy in the form of food (sugar, starch, fat and protein) into heat and into other forms of chemical energy to support life and to do work.

The burning process in organisms is less violent and goes on at a much lower temperature than in engines. It is called *respiration* or breathing.

Thus: Carbohydrate + oxygen = Carbon dioxide + water + energy.

Both plants and animals respire but it is more difficult to show the process in plants than in animals. This is because, *first* the carbon dioxide, as it is produced, is used up by green plants in daylight, (see under 'Photosynthesis'), and *second* the water produced by respiration is masked by the excess water taken in by the root hairs and transpired mainly from the leaves (see under 'Transpiration'). Hence the giving off of carbon dioxide from a green plant can be demonstrated only in darkness. Special helpers of chemical change called *enzymes* take part in the process.

EXERCISES ON RESPIRATION

Exercise 1.—Take five similar-sized glass jars. Into 1 pour a little water (control jar); into 2 put some fresh germinating bean seeds; into 3 put some living roots, freshly cut from young vigorous plants; into 4 put some living woody stems; into 5 put some freshly obtained green leaves. Make the jars air-tight by covering them with ground glass plates smeared with vaseline. Set them in darkness. After 24 hours pour into the jars equal volumes of baryta water or lime water; replace the glass lids, shake the jars well, and compare the degree of milkiness produced in each case.

Exercise 2.—Repeat or duplicate the experiment, keeping the jars exposed to bright light.

Exercise 3.—Suspend three or four fresh, vigorous leaves, e.g., privet, by threads upon the lightly fitting cork of a large bottle containing a little lime water, and expose them to bright light. Then cover the bottle with black cloth for a few hours, or place it in a dark cupboard. In light the lime water remains comparatively clear, but in darkness a scum develops on the surface, owing to respiration no longer being masked by the re-absorption of the carbon dioxide in the process of carbon fixation which goes on in the light.

A moment's reflection shows that plants do a considerable amount of work: they lift their parts against gravity, lift water and minerals from the soil, swell and push out structures in growing, move tendrils and twining stems through the air, force roots through hard soil, and even lift rocks or kerb stones. Further, they are continually forming new tissue in the process of growing and reproducing. For their work plants require a supply of energy or power just as do machines or animals. In plants, as in animals, the most conspicuous indications of respiration are the absorption of oxygen and the release of carbon dioxide and water. As the carbon, of the carbon dioxide which escapes, is derived from compounds within the body of the organism, it is obvious that respiration must result in a decrease in the dry weight of the plant or animal. Respiration takes place in all living parts of plants. Ordinarily the parts of plants above ground obtain an adequate supply of oxygen, but the roots of crops are often seriously injured through a deficiency of fresh air in the soil, this being due chiefly to bad drainage, and sometimes to insufficient cultivation of heavy soils. Seeds buried too deeply are liable to germinate unsatisfactorily through a deficiency of fresh air for respiration. (See page 14.)

In young vigorous growing parts, such as germinating seeds and expanding buds, respiration goes on vigorously, while in dormant buds and dry seeds little or no respiration is observable. The light supply has little influence on the rate of respiration but temperature has a marked influence. As the temperature rises up to about 30° C. so the rate of respiration increases. As the temperature rises above 30° C., the enzymes (organic catalysts necessary for helping the chemical changes) tend increasingly to become inactive, so the respiration rate after a time slows down ultimately stopping altogether and death of the plant occurs.

Phosphate is necessary for respiration. Some important intermediate products of respiration are phosphatic organic compounds. The chemical changes which go on during respiration proceed, in many respects, in the reverse order to those going on in the food-making process of plants called photosynthesis.

If carbon dioxide accumulates during respiration, then the process slows down. This is important in the keeping of stored apples. If boxes of apples are stacked in tiers at close intervals in a storage shed, then the carbon dioxide given off in the respiration of the apples excludes to some extent the oxygen of the air, slows up ripening and the apples keep much longer than if special arrangements were not made. It has been found that apples keep best in an atmosphere containing about 5 per cent oxygen.

Unlike an ordinary animal, a plant is not killed immediately by an absence of oxygen. If the air surrounding a plant lacks oxygen, the plant can still get some of the energy it needs for living by what is called *anaerobic respiration,* a type of breathing not requiring oxygen. Some kinds of lowly plants, e.g., some bacteria and yeasts, carry on this anaerobic respiration as a normal process.

If a soil is water-logged, i.e., lacks air, soil bacteria may, by anaerobic respiration, get their energy from nitrogen compounds forming nitrogen gas which is lost to the atmosphere. From the farmers' point of view this is a very undesirable state of affairs. (See page 186.)

Yeast is used by bakers to make dough rise and by brewers to turn sugar from germinated barley into alcohol for beer. Yeast is a colourless single-celled organism and gets its energy from sugar by turning it into alcohol as well as into carbon dioxide. This is not an efficient method of obtaining energy as only a small proportion of the energy in the sugar is released. The energy left in the alcohol can be released by burning it in a spirit stove or in an internal combustion engine.

Anaerobic respiration can be briefly represented as follows:—
Carbohydrate = Carbon dioxide + alcohol + a little energy.

In highly organised plants, oxygen is usually necessary for the release of energy except for short periods. Every living cell needs fresh air with its oxygen, air which is obtained chiefly through the pores (stomata) in the leaves, the lenticels in the stem, and the root hairs. With the last mode of entry the air is dissolved in the soil water. In the case of roots respiration provides the energy required especially for the uptake of minerals by root hairs. (See Chapter 4.)

As we saw in Chapter 2, seeds will not germinate in the absence of oxygen. Nevertheless seeds will continue to *live* for some time in the absence of oxygen. In such a case the necessary energy is released by anaerobic respiration.

To Demonstrate Anaerobic Respiration

Exercise 4.—Peel off the coats of soaked peas to avoid the air included between the seed coat and the cotyledons. Fill a small test-tube with mercury, invert in a shallow dish of mercury and pass the peas under the mouth of the test-tube to float to the top of the mercury in the tube. Leave for 24 hours. Test the gas in the test-tube for carbon dioxide by slipping a small piece of potash under the mouth of the tube and note whether or not the gas is absorbed.

Exercise 5.—Taking a 5 per cent sugar solution place it in a flask suspended over a steam bath or in a similar warm place. If a pinch of potassium phosphate is added, the anaerobic respiration is assisted. Fit the flask with a leading tube, and, when action is observed, put a test-tube of lime-water on to the end of the tube. Note the effect. Note also the smell of the contents of the flask.

If anaerobic respiration continues for long in a plant, alcohol accumulates, the plant becomes poisoned and it will die.

That the energy released in anaerobic respiration is less than in aerobic respiration is shown in a compost heap. If the heap is poorly aerated, the anaerobic respiration of the fungi and bacteria inside the heap produces little heat. On the other hand if sufficient air is present in the heap, aerobic respiration goes on and the temperature is higher. In the latter case decomposition is more rapid. (See Chapter 12.)

A similar situation exists where silage is made, but the opposite result is desired, namely no aerobic respiration and only enough anaerobic respiration to produce preservative substances in the stored food.

Where does this energy, released in animals and plants by their burning of food, come from? Initially it comes from the sun. Englishmen eating New Zealand lamb may be said to be getting their energy from New Zealand pastures which fed the lambs. Plants are able to fix the energy of sunlight, making it available for themselves and for animals including man, and they do it mainly in their leaves. As leaves are so important as processing factories for high energy goods which we call food substances, let us examine the structure of a leaf.

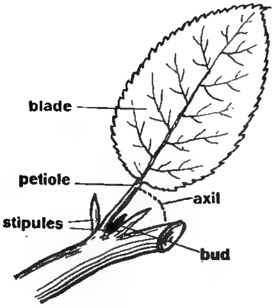


FIG. 25. Parts of a typical leaf

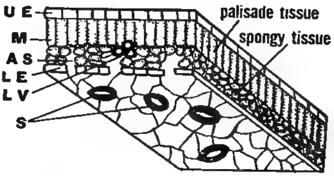


FIG. 26. Leaf structure: UE, Upper epidermis; M, Mesophyll; AS, Air space; LE, Lower epidermis; LV, Leaf vein; S, Stomata

THE LEAF

A typical foliage leaf consists of the following parts (Fig. 25):—

1. *Blade or lamina*—the broad expanded portion, which assumes a great variety of forms, and in which the work peculiar to the leaf is carried out.

2. *Petiole*—the slender stalk connecting the lamina with the stem, and enabling the blade to expose itself to suitable light. Frequently it is missing, in which case the leaf is described as sessile.

3. *Sheath*—a flattened, more or less, sheathing basal portion, which is frequently absent, but which is especially well developed in many grasses, docks, buttercups, and the carrot family.

At the base of the leaf wing-like outgrowths of varied form often arise, e.g., clovers, pea, apple. These structures, which are known as *stipules,* assist in normal leaf functions if they are green, as in some peas. In the false acacia (*Robinia*) they exist as spines while they often serve as scales to protect the buds, e.g., poplars, where the outer bud scales are stipules.

Exercise 6.—Examine the leaves of the chief farm plants and weeds of your district. Note their shape, and the presence or absence of sheath, petiole, and stipules.

Exercise 7.—Select one leaf of each of the four following kinds:— (a) typical, as in apple or peach, (b) grass, as in ryegrass or barley, (c) clover, as in red clover or lucerne, (d) compound, as in potato or kowhai. Make a large drawing of each kind showing its attachment to the stem and label all the parts.

Note especially the contrast in arrangement of veins in the grass, a monocotyledon, with the arrangement in the other leaves, those of dicotyledons.

LEAF STRUCTURE

The following parts can be distinguished (Figs. 26 and 27):—

1. *Epidermis*—a layer of transparent flattened cells covering both surfaces. The outer walls of these cells are usually impermeable to water and gases because of the presence of a substance called cutin, which resembles cork in some respects. Cutin is especially well developed in plants growing in exposed situations and in those of an evergreen character, while it is little developed in water plants.

At certain points on the epidermis occur narrow oval apertures known as *stomata* (sing. *stoma*).

2. *Mesophyll* or ground tissue—the green spongy material between the upper and the lower epidermis. The upper portion (palisade tissue) of the mesophyll consists of regularly shaped, closely packed cells of cylindrical form, while the lower portion (spongy tissue) contains large spaces between the irregular cells. Most of the cells contain green colouring matter in oval-shaped bodies called chloroplasts. The spaces between the cells contain air, and communicate with the atmosphere by means of the stomata.

3. *Leaf veins*—woody strands which run through the mesophyll. It must not be thought that these are similar in structure to the veins of animals. They are extensions of the vascular tissue of the stem and, being woody, act as a firm framework or skeleton for the support of the soft ground tissue. Through them also the sap is conducted to and from all parts of the leaf. The

veins of the leaf differ from the vascular system of the stem in being without cambium, for which there is really no need in view of the limited growth of the leaf. In dicotyledons the veins branch repeatedly to form a fine network of strands, while in monocotyledons the strands run parallel to each other from the base to the tip of the leaf. The former arrangement is described as reticulate, the latter as parallel.

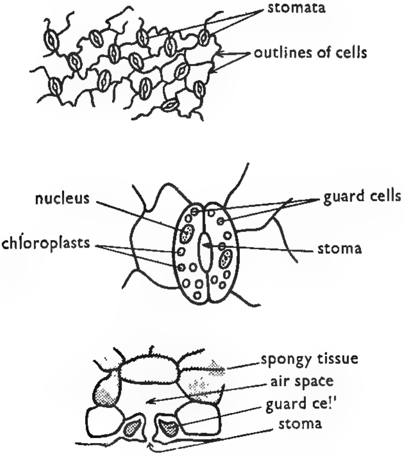


FIG. 27 *Top*, Surface view of stomata on under-surface of a leaf; *Middle*, Surface view of a single stoma; *Bottom*, Side view of a stoma

TO EXAMINE THE LEAF STRUCTURE

Exercise 8.—Boil some leaves, e.g., privet, in medium strength caustic soda solution for 10 minutes. Holding the leaf under water cut off a strip round the margin. With the aid of a needle the leaf is then readily separated into three parts: (1) upper epidermis, (2) lower epidermis, (3) mesophyll or middle tissue, containing the veins, which can be teased out as woody fibres from the mass of soft green tissue.

TO SHOW THE PRESENCE OF STOMATA

Exercise 9.—Drop some leaves into water which is just below boiling point, and note the appearance of bubbles on the surface of the leaf. These are bubbles of air which have escaped from the interior of the leaf through the stomata. By noting the number of bubbles on the upper and lower surfaces we obtain an idea of their relative frequency in each epidermis. Several kinds of leaves should be tried to discover which surface of the leaf generally possesses the greater number of stomata.

LEAVES AS FOOD MAKERS

In Chapter 4 we learned how plants get their water and minerals from the soil. Now, having studied leaves, we shall learn how plants, chiefly by means of their leaves, take carbon dioxide out of the air and combine it with water and minerals from the soil to make food; how the low energy substances, carbon dioxide, water and mineral compounds are turned into the high energy substances, carbohydrates, fats, and proteins; how a catalyst called chlorophyll, the green colouring matter of plants, is the means by which the energy of sunlight is trapped to make this build-up of energy.

This process of fixing the energy of sunlight in the form of stable chemical compounds, the turning of light energy into chemical energy, the synthesis (putting together) of sugar and other substances from carbon dioxide and water in leaves by the energy of sunlight is called *photosynthesis*. It is a unique process and of supreme importance; unique because there is no alternative to it in nature or in a laboratory; and of supreme importance because without it life on earth could not go on.

More than half the dry weight of plants consists of carbon. The main source of this large quantity of carbon is the carbon dioxide gas of the air, which is absorbed by means of the leaves. After entering the cells of the leaf, mainly, if not wholly, through the stomata, the carbon dioxide combines with a certain proportion of water forming soluble carbohydrates, e.g., sugar, oxygen also being set free during the process, which may be presented as follows:—

Carbon dioxide + water + light energy = carbohydrate + oxygen.

This equation gives the beginning and the end of the process. In between there is a large number of chemical changes which go on very rapidly. By the use of radioactive* isotopes of oxygen and carbon to trace the chemical changes, the broad outlines of photosynthesis have been discovered. Photosynthesis is seen to go on in two main and distinct stages, the *first* being that inside the chloroplasts where the light energy is trapped and hydrogen from water is made available, and the *second* taking place outside the chloroplasts somewhere in the leaf cell where the hydrogen combines with carbon dioxide.

---

* A radioactive isotope is an element which has been exposed to radioactivity making it radioactive. It differs slightly from the normal form of the element in atomic weight but it behaves chemically in the same way as the normal form. The presence of a radioactive isotope in a plant can be detected and its progress traced by its effect on photographic plates or by means of a Geiger counter.

It has been proved that the oxygen evolved in photosynthesis comes only from the water. Chlorophyll, in oval-shaped bodies called chloroplasts situated most abundantly in the palisade tissue of leaves, captures the energy of sunlight. This energy is used to remove hydrogen atoms from water (derived from the soil) and to join them to carbon dioxide gas (derived from the atmosphere). This results in energy being stored, the most common form of storage being the carbohydrates, sugar and starch.

From experiments to show the amount of light necessary to add hydrogen to one molecule of carbon dioxide gas, it appears that it takes 8 to 10 steps to fix the energy chemically.

A phosphorus organic compound formed during photosynthesis then combines with additional lots of carbon dioxide to form other compounds which are built up into carbohydrates, fats and proteins. So carbohydrates such as sugar and starch are not the only direct products of photosynthesis. Nitrates, sulphates and phosphates brought up in solution in the soil water are built into the intermediate phosphorus compounds to make more complex compounds, the proteins, containing in addition to carbon, hydrogen, and oxygen the elements nitrogen, sulphur and often phosphorus. Calcium and potassium salts also play some part in photosynthesis.

The relative amounts of carbohydrate, fat and protein formed as a result of photosynthesis depend upon the stage of growth of the plant and the conditions of its growth. Thus in the growing regions of a plant the greatest demand is for protein to build protoplasm, so photosynthesis produces chiefly protein for those regions. In more mature parts, and in mature plants generally, photosynthesis produces mainly carbohydrates such as starch which is stored in seed or root or stem.

Some of the substances formed by plants are of little or no use as animal food. As we shall see in Chapter 18, pasture consisting of young leaves is rich in protein whereas pasture consisting of old leaves and stems has less protein and is richer in carbohydrate, especially cellulose. Further, as stems develop, their cellulose cell walls become coated with a substance called lignin which is indigestible, so that advanced stemmy growth is of little use as food for animals. This is how Sir J. A. Scott Watson puts it:* 'A cow can derive quite a large amount of energy from eating a cotton shirt or a sheet of blotting paper! But even the cow can make nothing of saw-dust, because wood is heavily impregnated with lignin.'

We may regard starch as the first visible product of carbon fixation, and in experimental work its presence provides evidence of carbon fixation. Actually, starch is formed in the leaves as a means of temporary storage. Since sugar is soluble, its accumulation in the cells of the leaves would result in a viscid treacly sap unsuited for translocation. Starch, being insoluble, does not affect the sap in like manner, and so, during the day when the leaves are most active the sugar is converted into starch, which is reconverted into sugar, and passes out of the leaf. (See Chapter 6).

To Bleach Leaves

Exercise 10.—Select nearly mature, thin, clear, green leaves, e.g. primrose, mallow, young oats. Place these (flat or rolled, but not crumpled), in a large test-tube and cover with methylated spirits. Then stand the test-tube in a beaker of water which has been boiling, first extinguishing the flame for safety. The leaves when taken from the spirits will be brittle, and liable to break in handling, but by placing them in water for a minute or two the brittleness is removed. The bleaching of thick or leathery leaves, which do not release the chlorophyll readily, is hastened by boiling them in water for a minute or two before placing them in methylated spirits.

To Test a Leaf for Starch

Exercise 11.—Bleach a leaf as described above, and pour dilute iodine solution over it. If there is abundance of starch in the leaf it becomes nearly black, if little starch it is a dirty bluish, if no starch is present the leaf turns brownish because of the presence of proteins.

Is Light Required for Starch-Making?

Exercise 12.—Set some pot plants, e.g., broad bean, potato, primrose, in darkness for at least a day, by covering them with a close box or by placing them in a dark cupboard. After returning the plants to light, select one or more young leaves and fasten, with slip-on fasteners, a strip of opaque paper across the middle of both surfaces of each leaf. Leave for a few hours in direct sunlight. Pick the leaves that have been partially shaded and bleach them immediately after picking, or boil them for a few minutes to prevent changes in the leaves if the testing is delayed. On testing the bleached leaves with iodine solution compare the coloration of those parts kept in darkness with those exposed to light.

Is Chlorophyll Necessary for Starch-Making?

Exercise 13.—Note whether the colourless veins of leaves become dark when the rest of the leaf is black with the iodine test.

---

* *Agriculture* (British Ministry of Agriculture) Nov. 1952, p. 353.

Test variegated leaves, e.g., variegated varieties of geranium, privet, nasturtium, coleus, and maples for starch. Before bleaching these leaves make a careful drawing showing the green and non-green areas in the leaf, and compare these with the areas in which starch is present.

It should be remembered that certain coloured leaves such as beet contain masked chlorophyll, and hence are unsuitable for this test.

Exercise 14.—Grow seedlings in darkness so that they do not develop green colouring. Then put them in the light for a day and test some of the leaves for starch. Leave them in the light till the leaves turn green, then test them (See Fig. 28.)

IS CARBON DIOXIDE NECESSARY FOR STARCH-MAKING?

Exercise 15.—Taking a plant, growing either in a pot or in the garden, selected for its supply of young but fully developed soft leaves, cover the plant so that it will be in darkness for 24 to 48 hours. Uncovering the plant take two or more suitable leaves and place them still attached to the plant, in an atmosphere free from carbon dioxide by the following means. (See Fig. 28.)

Into a large conical flask put enough 10 per cent sodium hydroxide or potassium hydroxide solution to about one eighth fill the flask. Roll one of the selected leaves, insert it into the flask, being careful to prevent it touching the solution, and fit the stalk of the leaf into a halved, one-hole stopper which is then fitted into the neck of the flask. Pack the stalk with cotton-wool and seal with vaseline. Set up a control flask in a similar way except that water is used instead of the solution. After the flasks have been a few hours in sunlight, pluck the leaves, remove them from the flasks, and test them for starch. Is there any difference between the leaves under the different treatments? What do you conclude?

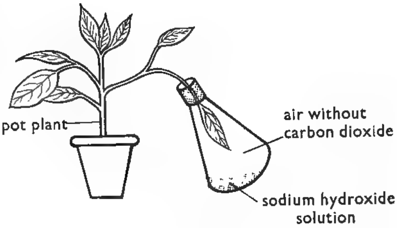


FIG. 28. Apparatus to determine whether or not carbon dioxide is necessary for photosynthesis

WHAT GAS IS GIVEN OFF BY GREEN LEAVES?

Exercise 16.—Bubble carbon dioxide gas through water in a large dish so that some of the gas may be taken into the solution. Place some fresh, vigorous water plants under an inverted funnel in the water in the dish. The funnel leads into a test-tube of water as shown on the right of Fig. 29. The gas which is released from the leaves, when placed in bright sunlight, collects in the test-tube, where it displaces the water. The gas may be proved to be oxygen by its causing a glowing splinter of wood to burst into flames.

(NOTE.—To give a greater available water space the funnel should be raised above the floor of the dish. Less vegetation than is shown may give better results.)

On the left-hand side of Fig. 29 an alternative method of carrying out this experiment is shown. The bent glass tubing which carries away the water as the gas is formed must reach well down into the glass flask, which at the start is completely filled with water through which carbon dioxide has been passed.

Exercise 17.—Find whether the gas is given off in darkness, by covering the apparatus with a black cloth, and noting if the bubbling stops after a time. Then set the apparatus in bright light again.

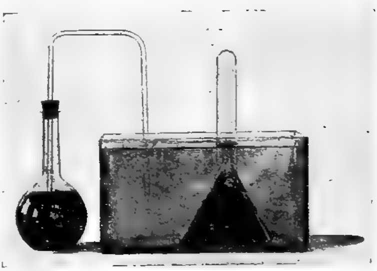


FIG. 29. Two methods of collecting the gas given off by leaves. Water plants such as Elodea are used in the experiment

CONDITIONS OF PHOTOSYNTHESIS

1. *Light* is an essential factor. The carbon compounds are stores of energy which have been derived from the sun as light. Food is taken by animals, including human beings, to give energy; coal and wood are important sources of energy. All the energy of animal food, of wood and of coal arises directly or indirectly from the photosynthesis which takes place in green leaves. It has been shown that ordinary daylight is more than adequate for the purpose, and can be reduced to one-twelfth without ill effect, so it is evident the plant is adapted to the worst light conditions it is likely to find. Light which has passed through a leaf is practically useless for vegetation. Thus one crop will not grow in the shade of another. A dense crop, by shutting off the supply of direct light to smaller plants, effectually prevents their growth, or, as the farmer says, 'smothers them'. This is often the easiest way of cleaning weedy land. However, apart from crop plants, there are many plants which grow best in partial shade, e.g., most ferns, and young New Zealand native trees. Plants may be grown under artificial light, e.g., electric.

Of the light energy falling on green plants only 1 per cent to 2 per cent is turned into chemical energy stored in the plants. To make the most of this meagre amount of energy, a farmer must grow his crops so as to store the greatest possible amount of sunlight per acre. He must keep down weeds which shade crops; he must grow his crops with the best spacing to avoid overcrowding on the one hand and to ensure there is no bare ground on the other; he must make sure there is sufficient water and dissolved minerals in the soil. Scientific research workers must help farmers by breeding plants capable of absorbing sunlight to the maximum extent, plants that can grow under poor conditions, and plants that can withstand attacks of diseases and pests.

2. *Chlorophyll,* i.e., the green colouring matter of plants, is essential for carbon fixation. The roots, the flowers, and the white portions of variegated leaves take no part in the process. The leaves of purple cabbage, red beet, and many other plants have coloured sap. This masks the chlorophyll, which is, however, abundant, and so carbon fixation can be carried on as readily as in ordinary green leaves.

Plants grown in the dark for some time lose their green colour because the production of chlorophyll is dependent upon light. They assume a pale yellow, sickly appearance; their internodes become very much elongated or drawn out, and the leaves remain small and scaly, for the plant has devoted much of its energy in the formation of long stems which may serve to bring it to the light. Such plants are described as *etiolated,* or drawn.

Plants grown in light may be of a sickly yellowish appearance if there is a lack of iron, which is necessary for the formation of chlorophyll. This condition due to the lack of iron is known as a *chlorotic* condition, and may readily be corrected by supplying an iron salt.

3. *Carbon dioxide* must be present in the air surrounding the leaves. Plants grown in air from which the carbon dioxide has been removed do not increase in dry weight, and after a time die from starvation. In the ordinary plant carbon dioxide is absorbed through the stomata and, as these are very numerous, large amounts of carbon dioxide are absorbed from the air. Though the proportion of carbon dioxide in the air is very small, 0.03 per cent by volume, yet there is no danger of the supply being exhausted by plants, for it is continually being renewed by the breathing and decay of organisms, and by burning processes.

As photosynthesis proceeds very rapidly during daylight, green plants absorb the carbon dioxide produced by their own respiration as well as that produced by animals and other processes. Hence the amount of carbon dioxide in the atmosphere stays about constant. If the proportion of carbon dioxide in the air is increased artificially to one per cent or so, and the other conditions are suitable, photosynthesis is correspondingly increased.

4. A supply of water and the minerals dissolved therein are also necessary for photosynthesis. The minerals specially necessary are phosphorus, potassium, calcium, magnesium and iron. Phosphorus is a constituent of intermediate products as well as being in many of the final proteins. Magnesium is a constituent of chlorophyll and iron is necessary for the formation of chlorophyll. Potassium and calcium in some way help the process.

5. The rate of photosynthesis varies with the *temperature*. The process goes on slightly at one or two degrees above freezing point, and increases in rate up to about 25° C. beyond which it decreases until at 56° C. it ceases because of the death of the plant.

Comparison of Photosynthesis and Respiration

As these are, to a certain extent, opposite processes it is helpful to summarise the contrasting points:—

Photosynthesis	*Respiration*
1. Energy is stored.	1. Energy is released.
2. A process concerned with building up plant substance.	2. A process involving the breaking down of substance.
3. Plant gains in dry weight.	3. Plant loses in dry weight.
4. Occurs only in green parts of plants.	4. Occurs in all parts of plants.
5. Occurs only in light	5. Occurs both in light and darkness.
6. Carbon dioxide passes in, oxygen passes out.	6. Oxygen passes in, carbon dioxide passes out.
7. Starch is (usually) formed.	7. Carbon dioxide is formed.

ADDITIONAL NOTE ON PHOTOSYNTHESIS IN RELATION TO LIGHT

Not all light is visible to the human eye, but it happens that it is the visible light that is used in photosynthesis. This light varies from low wave-length, light showing violet when passed through a glass prism, through light of intermediate wave-length, blue, green, yellow and orange, to high wave-length, the light showing red. (See Fig. 30.)

The energy of light is measured in packets called *quanta* (sing. *quantum*) and a quantum of violet light contains twice as much energy as one of red light. In strong direct sunlight it is the red rays that are chiefly concerned but in cloudy weather the violet rays are the most important.

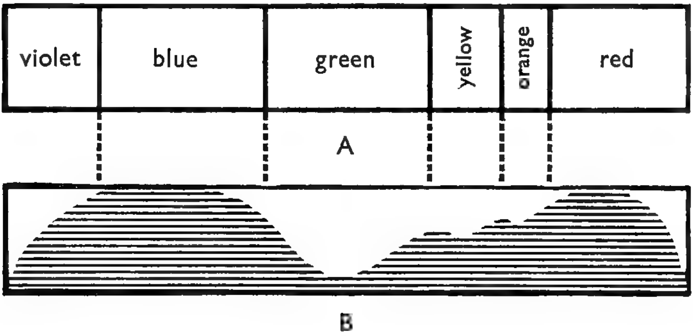


FIG. 30. A: Distribution of colours in the spectrum of sunlight. B: Spectrum of sunlight after passing through a leaf. (The black parts indicate proportions of light absorbed in each region of the spectrum)

(Adapted from *A Textbook of General Botany*, Smith and Others, Fig. 97)

WHY MOST PLANTS ARE GREEN

Light on leaves can be reflected or transmitted or absorbed. Only light that is absorbed can produce chemical change. Substances appear coloured because of the light they reflect and transmit not because of that which they absorb. Thus leaves appear green because they reflect and transmit green light, the blue and the red being the chief kinds absorbed. However, light in the rest of the visible spectrum is absorbed a little and so does help photosynthesis to some extent. (See Fig. 30.)

HOW ABSORBED LIGHT IN GREEN LEAVES GIVES ENERGY FOR CHEMICAL CHANGE

If light, absorbed by a green leaf, is to carry out food-making, it must affect the atoms of the substances in the leaf. Now each atom is made up of a positively charged nucleus around which negatively charged electrons move in regular paths called orbits. For each quantum of light absorbed, an electron is forced to move in an orbit some distance further away from the nucleus of the atom than normally and the energy of the atom is increased beyond the normal amount. On the return of the electron to its former position, energy is released for chemical change, the most prominent change being the removal of hydrogen atoms from water and the joining of these to carbon dioxide.

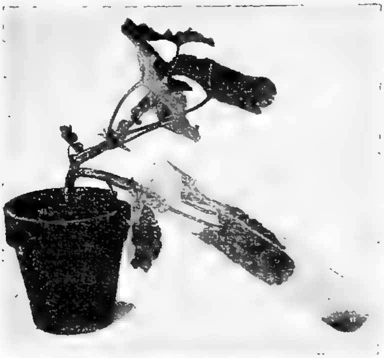


FIG. 31. Collecting the water transpired from a leaf

TRANSPIRATION

The continuous invisible loss of water in the form of vapour which is going on from all parts of ordinary plants is termed transpiration. The amount of water which transpires from the leaves is considerable: a sunflower $3\frac{1}{2}$ feet high has been found to exhale a pint a day in summer; a single maize plant may remove more than 50 gallons of water from the soil in a season; an acre of apple trees may transpire about 500 tons of water during one month in midsummer. This extensive loss of water by transpiration would soon cause death if more water were not absorbed to replace that given off. As previously described the necessary absorption takes place in the roots. Between the roots, where the water enters, and the leaves where it escapes, there is a continuous upward stream of water, termed the transpiration current. The current, which moves at from 6 inches to 6 feet per hour, travels in the wood, and in perennial stems it travels, not in the heartwood, but in the youngest outermost annual rings.

The chief escape of water is through the openings of the stomata, and as these are in greatest abundance on the leaves the latter become the chief organs of transpiration. The rate of transpiration varies with the following external conditions:—

1. The intensity of the light. At night and in darkened rooms the amount of water transpired is small in comparison with that given off in bright sunlight.

2. Movements of the air, such as draughts and wind, increase the amount of water lost by the leaves.

3. The amount of water in the surrounding atmosphere greatly influences the rate of transpiration: when the air is saturated, as on a dull day, transpiration almost ceases, while in a dry atmosphere, even if cold, considerable loss of water occurs and, as low temperature checks the absorption of water by the roots, the loss due to transpiration may not be balanced by the root absorption, in which case leaf injury results.

It has already been remarked that plants can absorb the essential mineral substances only in weak solutions. Part of the water absorbed is used as a food material in building up tissue, but to obtain an adequate supply of the mineral substances much more water has to be absorbed than is required for direct nutrition. In transpiration the plant gets rid of this excess of water, which has served the plant as a means of transporting minerals to the leaves.

Exercise 18.—Slip a large, dry test-tube over a leaf or leaves of a vigorous plant growing in the light, and then plug the mouth of the test-tube with cotton wool (Fig. 31). After a time drops of water appear on the sides of the test-tube and, under normally favourable conditions, there will soon be a quantity of water in the bottom of the test-tube as a result of the accumulation of the drops.

Exercise 19.—For observations of transpiration a *Potometer* should be set up as shown in Fig. 32. To prevent air from getting into the vessels of the wood of the leafy shoot used, remove a portion of the cut end after it has been placed under water so as to expose a freshly cut surface. Keep it under water while its cut end is passed through a hole in the left-hand cork, by the following method:—

Taking a cork borer of a size just large enough to put the shoot into it without stripping the bark it is pushed through the hole in the stopper from beneath. Putting the shoot into the borer from above, the shoot is pulled through the stopper to leave the shoot gripped in the stopper. A glass tube, bent at right angles as shown, is inserted in the right-hand cork. The corks are then inserted into a U-tube full of water. The pressing in of the corks causes some of the water in the U-tube to fill the glass capillary tube. Further, if a glass rod (called a 'plunger') has been fitted to pass through the right-hand cork, by moving the plunger inwards or outwards, the length of water in the glass tube can be regulated as desired. Care must be taken to make all points of the apparatus water-tight—this can be done by the use of plasticine or vaseline. As the shoot transpires, water is drawn from the horizontal glass tube to replace that removed from the jar, so that by noting the rate of movement of the water in the horizontal tube, we can form a comparison of the rate of transpiration under different conditions. A graduated scale should be attached to the horizontal tube: for this purpose a strip of stout paper marked in centimetres may be used. When set up, the potometer should be placed

(i.) in bright sunlight.
(ii.) in darkness.
(iii.) in still air.
(iv.) in a draught, and a note made of the distance the water travels backwards in the glass tube in a given time.

NOTE.—When the potometer is first placed in the sun the warmth expands the water, which therefore moves forwards instead of backwards at the start. Hence no record should be taken for the first ten minutes following changes in temperature.

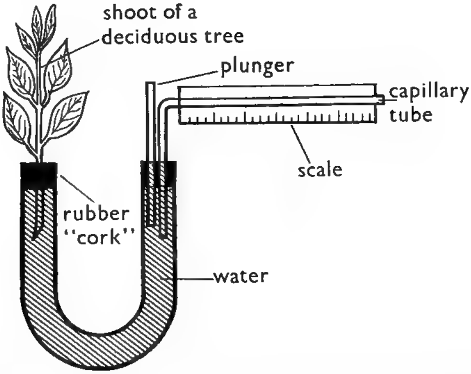


FIG. 32. Potometer: Apparatus for determining the transpiration of moisture under various conditions

Transpiration which goes on at a greater rate than that of absorption is, however, highly dangerous. At first this condition causes the plants to 'wilt', i.e., to become flaccid and droop—a result which is not infrequent in bright, hot weather in dry soils. Wilting is also apt to arise from root injury, such as occurs in transplanting, or from the attacks of insects, or of fungi, e.g., finger-and-toe disease of cruciferous crops.

HOW STOMATA OPEN AND CLOSE

Two sausage-shaped cells, termed *guard cells,* are joined together at the ends in such a manner that a slit-like opening, the stoma, is left between them. (See Fig. 27.)

When these guard cells become full of liquid they are said to be turgid. This causes them to curve outwards and enlarge the opening through which the vapour passes. The reason lies in the fact that the structure of the cells allows them to move only in a particular direction. When turgid they bulge away from each other; when they are partly empty and flaccid they become linear and almost touch each other, with the result that the stoma decreases in size. This happens when transpiration is so active as to reduce the water in the guard cells, or when there is a deficient supply of moisture. The fact that the guard cells contain chloroplasts explains why sunlight promotes transpiration: the guard cells work like the other green cells of a leaf during daylight to produce sugar. This promotes osmotic activity, which in turn causes the cells to become turgid, and thus the stoma opens. Stomata practically close in darkness.

Thus the leaves of most green plants cannot help losing water through the stomata during daylight for photosynthesis demands that stomata be open to let in air with its carbon dioxide and to let out most of the water that brought the necessary mineral salts from the soil.

It might be thought that a plant with leaves reduced in size and in number would have reduced transpiration. That this is not so is shown by the fact that the number of stomata per unit area is greater in plants specially adapted for growing in soil with little available water, plants called *xerophytes,* than in plants used to a good water supply, the *mesophytes.*

Xerophytes transpire more than mesophytes but as the wilting point is reached the protective structures of xerophytes enable them to reduce the water loss more efficiently than mesophytes. 'Shade' leaves have fewer stomata and transpire less than 'sun' leaves. For example:—

	Habitat	Number of stomata per unit area	Intensity of transpiration
Asperula glauca	Russian steppe	100	100
Asperula odorata	Russian forest	14	46

Again, the stomata are often much more numerous on the lower surface where they do not receive the direct sunlight.

STRUCTURES WHICH HELP TO REDUCE TRANSPIRATION

The leaves of most evergreen plants have a *thickened skin,* a layer of clear cells being developed below the upper epidermis. Sometimes, as in the cabbage tree (*Cordyline*) the stomata are sheltered by being placed in grooves or depressions in the leaf.

A *covering of woolly hairs* reduces the loss of moisture by hindering the escape of the water already transpired. In general a hairy plant tends to become less hairy in a moist situation, and more hairy in a dry situation.

Many *leaves are folded or rolled* so as to enclose the stomata in an air-still tube from which transpired water does not readily escape, e.g., chewings fescue, tauhinu, marram grass, pine.

Many leaves are covered with a *waxy bloom,* e.g., broad bean, cabbage, swede, onion, lupin. Experiments show that when the bloom is rubbed off there is a greater loss of moisture than from similar parts untouched. These 'adaptations' check transpiration under extremely dry conditions, not when soil moisture is freely available. Also some plants with these adaptations have them less fully developed when they are growing under conditions of continuously good water supply than when they are in their normal habitat.

PLANTS WITHOUT CHLOROPHYLL

Some plants have no chlorophyll, e.g., fungi, many bacteria, and a few flowering plants. From what has been said above it is evident that such plants cannot carry on photosynthesis, and consequently cannot manufacture the complex carbon compounds which are essential for nutrition. These complex compounds may be obtained either from living organisms or from decaying organic matter. In the former case the plants are called *parasites,* in the latter case they are *saprophytes.* Dodder and broom rape are examples of flowering plants which, being deficient in chlorophyll, are practically total parasites.

Dodder (Fig. 33) is an annual, and produces small, white, bell-shaped flowers. The seeds from these germinate late in the spring when the plants which serve as hosts have already developed their shoots. The slender root pushes its way into the earth and the young thread-like stem rises above it. If it finds no other living plant near, it dies, but should one be present, the dodder shoot twines round the stem, and from the points of contact suckers are formed which penetrate the host and suck the sap, which contains elaborated food materials. Then the root of the dodder dies, and the plant lives by its suckers alone. The thin stems resemble a tangled mass of yellowish horse hair. It is spread mainly by the use of farm seed containing dodder seed as an impurity.

Broom rape (Fig. 33) is like dodder in being parasitic, but differs in that its suckers attach themselves to the roots of the host plant. Above ground it consists of an erect, thick, fleshy, pale brownish stem, from 6 to 18 inches in length, which bears small pointed scale leaves and a spike of dirty reddish flowers. An average plant produces some 35,000 seeds, which, being small and light, are easily scattered by the wind. Hence the pest should not be allowed to ripen its seeds.

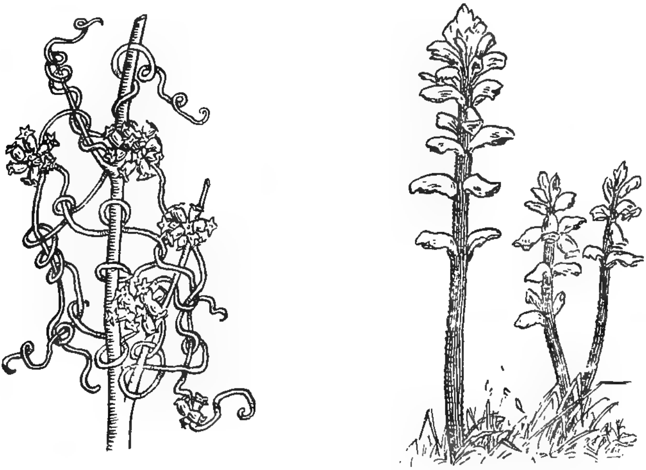


FIG. 33. Parasitic plants: *Left*, Dodder, a stem parasite. *Right*, Broom rape, a root parasite

CHIEF FUNCTIONS OF GREEN LEAVES

These functions may be summarised thus:—

1. To act as a laboratory for the manufacture of plant food from the carbon dioxide of the air and the water and dissolved minerals from the soil. In doing this the leaf acts as an organ for absorbing the energy radiated from the sun. The food material thus formed is transmitted to all parts of the plant where it is needed.

2. The leaves are the chief respiratory or breathing organs of the plant, taking in air with its oxygen.

3. From the leaves superfluous water is discharged when it has carried from the soil its load of mineral substance. The process of transpiration is, however, like that of respiration, a subsidiary function of the leaf.

Knowing this, one can better understand the necessity of caring for the leaves of crops to see that their work is not interfered with.

How the Work of Leaves is Interfered With

1. Some insects eat the leaves or part of them, chewing and swallowing them as food. Others again have sharp beak-like parts with which they suck the sap, which is to the plant what blood is to animals. The leaf, and consequently the plant, is more or less starved. The attacks both of chewing and sucking insects always lower the vitality of plants, and if severe or repeated may ultimately cause death. (For control of insects see Chapter 24.)

2. Diseases, due generally to fungi and sometimes bacteria, cause the leaves to turn yellow or brown in parts, or to become filled with holes.

3. The supply of sunlight may be insufficient. This is generally caused either by the plants being planted so thickly that they crowd each other and shut out light and air, or by weeds being allowed to grow and produce the same result.

4. Excessive watering or insufficient watering are each indicated by the leaves turning yellow and dropping off or drying up.

5. Dust sometimes chokes the leaves of house plants. This is easily remedied by washing or spraying.

THE FORMS AND ARRANGEMENTS OF LEAVES

The examination of leaves brings out many features which become intelligible as adaptations enabling the work of the leaf to be most efficiently carried out. The flattened form gives the leaf a large surface, and enables it to absorb the necessary supply of carbon dioxide and to catch a sufficient number of the rays of sunlight. There is a protective membrane, the epidermis, which prevents excessive loss of moisture. The spongy tissue with spaces communicating with the numerous stomata on the lower surface is specially fitted for the circulation of gases, which must occur to allow of respiration and carbon fixation. The branching veins carry water and its load of food material in solution to all parts and at the same time serve as a supporting framework. In seeking the reasons for the great variation in forms and arrangement of leaves, the need for sunlight must be kept in mind.

A leaf which is shaded, and consequently receives a poor supply of light, grows feebly, for of course photosynthesis is impeded. Hence we find that in many cases the leaves are arranged in a manner to avoid shading one another. Such an arrangement (which is termed a Leaf Mosaic) is exemplified:—

(1) In such plants as dandelion, daisy, and rib-grass, where the crowded leaves form a rosette, with the minimum of overlapping.

(2) In plants which creep along the wall or bank, e.g., ivy.

(3) In such plants as nettles, where the lower leaves have broader blades and longer stalks than the upper ones.

It may be further remembered that the form of leaves is also influenced by the necessity to withstand winds and to carry away rain from the blade.

Exercise 20.—Examine the cotyledons of the seedlings of farm and garden crops, and of weeds. Note whether they come above ground or remain in the soil. Note also any differences between the cotyledons and the first foliage leaves, and then find out as far as possible by observation and experiment, the reasons for these differences. Many of the reasons for the differences can be thought out from your previous study of the work of the green leaf.

Exercise 21.—To find whether cotyledons are essential for the development of the root and shoot of the embryo, cut the cotyledons off a germinating broad bean as soon as the parts have emerged from the seed coat. Note whether the root and shoot develop without them.

Exercise 22.—Examine the different types of scale leaves as seen on winter buds, on twitch grasses, on lily bulbs, and on onion bulbs. Try to connect the differences in structure with differences in function.

Exercise 23.—Examine all spines that you can find and determine whether they are modified shoots or modified leaves.

Exercise 24.—Make a similar classification into modified stems and modified leaves of all tendrils that you can observe.

VARIOUS TYPES OF LEAVES

There are various structures which, though sometimes very different in general appearance from ordinary foliage leaves, are to be regarded as leaves because of their origin and position, and also frequently because they bear buds in their axils. Certain of these modified leaves receive special names, as indicated below.

1. *Cotyledons,* or seed leaves, are the first leaves a flowering plant possesses. They are much simpler in form than the foliage leaves developed later. They are nursing or feeding organs, serving as:

(a) Mere storehouses of reserve food for the seedling until it is established, e.g., broad bean, pea.

(b) Organs of digestion to absorb the food stored in the endosperm of the seed and transport it to the growing regions, e.g., cereals and grasses.

(c) Often, as in turnip and marrow, the cotyledons come above ground, become green, and carry on the work of ordinary foliage leaves in addition to acting as storehouses of food.

2. *Bract* is the name given to a leaf which is found upon the stem where flowers and inflorescence occur. Often bracts cannot be distinguished from ordinary leaves except by their position, but often again they are small and poorly developed. The term glume is applied to the thin chaffy bracts which envelop the flowers of grasses and cereals.

3. *Tendrils*—the thin wire-like structures mentioned earlier, are sometimes modified leaves, e.g., pea, vetch.

4. *Scale leaves* are typically small brown membranous structures which provide protection to buds both above ground, e.g., fruit trees, and below ground, e.g., gladiolus corm, potato tuber, rhizomes of couch.

5. *Leaf spines*—That the thorns of barberry and some of those of gorse are modified leaves is seen from the fact that buds and shoots regularly appear in their axils.

6. *Floral leaves*—These are the highly specialised leaves which form the chief parts of a flower. They are not modified green leaves as is sometimes taught but are leaves of an origin as old as a green leaf or perhaps older.

READING

New Biology, No. 11, Oct. 1951
Science News, No. 22, Nov. 1951
* Mainly for the teacher

FILMS

(The National Film Library)
'Photosynthesis'
'Gift of Green'

6

Food Storage and Growth

TRANSPORT OF FOOD MATERIAL

The sapwood, cortex, and bast are the parts chiefly concerned in conveying food material from one part of the plant to another. The stream of sap conveying raw food material from the soil to the leaves travels through the wood. The food (sugars and proteins) manufactured in the leaves passes to where it is required for growth in stems and roots through the cortex and bast. Hence the removal of a complete ring of 'bark' (i.e., the tissue outside the wood) does not affect the upward flow of moisture and food material, but it cuts off the supply of elaborated food to all parts below the encircling wound which by remaining unhealed for any length of time starves the roots and sooner or later kills the plant. Plants will live a variable time after 'ringing' according to the amount of food stored in the portion below the wound, and if shoots arise below the ringed part, as in willows, gums, and certain fruit trees, their leaves will manufacture food, and as there is no break in the connection with roots, the plant will continue to grow.

Just above a ringed part there is often an abnormal enlargement of the stem arising because of the descending food-bearing sap being checked and accumulating. The thickening just above where the scions have been inserted in grafting is similarly explained. Cutting away a ring not only of bark but of sap wood will quickly kill a plant, unless shoots arise below the cut; for the flow of sap, both upwards and downwards, is cut off.

The fact that the inner bark (cortex and bast) provides a passage for the sap containing the plant food ready for immediate use shows that bark wounds such as are caused by the gnawing of animals, e.g., hares, or by the careless use of cultivating implements, may seriously interfere with the nourishment of the plant. Further, we can appreciate the severity of the damage done by diseases, such as apple canker, which tend to destroy a circling ring of bark, and so cut off the supply of nourishment to the parts below the affected area. We can also understand how sucking insects located on the bark do so much harm by depriving the plant of a portion of its food supply, for though the sucking organs of the pests are comparatively short yet they are long enough to reach the plant foods which are conveyed through tissue so near the surface.

Exercise 1.—In the spring or early summer remove from a willow twig, at about 2 inches from the base, a band 1 inch wide of the outer soft tissue, leaving only the hard, woody portion of the stem (this is ringing). Then set the twig in culture solution or in water, which should be changed frequently. When, after a few days, it begins to sprout, note that below the point where the band was removed buds and new roots develop slowly in comparison with the rate of development above the injury. As the buds above the injury are active, and bear leaves, the supply of necessary water must move upwards unchecked, and so must travel through the wood. The rapid development above the injured region shows that most of the food must travel downwards through the softer, outer portion of the stem, i.e., through the soft bark.

Exercise 2.—Revise or repeat the exercises under 'leaves as food makers' in Chapter 5.

Revise the results of, or repeat the work of testing seeds for starch, sugar, protein, oils.

Exercise 3.—Cut a potato tuber across and test for starch by dropping iodine solution on the cut surface. Cut a piece of tuber finely, boil the small pieces in water, and test the liquid for starch. Test potatoes for sugar (a) very young tubers, (b) mature tubers, (c) tubers which have developed sprouts. Cut a very thin slice from the outer portion of a potato tuber and test it with nitric acid for protein. Examine the layer of cork which forms the skin of the tuber. What is the use of such a corky skin? Will the peeling of potatoes affect their contents? Test the Jerusalem artichoke for inulin. If inulin is present the freshly cut surface of the artichoke will turn a yellow brown when iodine is applied to it. Test bulbs and corms for starch and for sugar, e.g., onion, gladiolus. Test for starch and sugar the roots of parsnip, kumara, carrot, turnip, and beet. If the test for grape sugar fails, test for cane sugar.

Exercise 4.—In winter cut transversely a last season's branch of apple and place the exposed section in iodine solution for a minute or so, and then wash it with water. Place another exposed section of the apple twig in strong nitric acid and examine for coloration. Is there any plant food stored in the dormant apple twig? If so, what are the substances stored? Similarly test peach and other dormant twigs.

Exercise 5.—Cut up into small pieces a portion of the swollen bulb-like stem of kohl rabi or the swollen stem of chou moellier and boil in water for several minutes. Then pour off the liquid and test it for starch and for sugar. In both these cases, as in all such testing, it is well to scrape or chop the material to be tested into very fine pieces.

PLANT FOOD AND ITS STORAGE

It is desirable to distinguish between what is called *elaborated plant food* and the *raw materials* out of which it is made. If by food one means the substance out of which the plant builds up new tissue, repairs waste, and obtains energy for its general life processes, then it is incorrect to speak of carbon dioxide, minerals, and water as plant food. The fact is, as already explained, that the green plant has the power of absorbing these substances, and of making from them new substances, carbohydrates, fats and proteins, which are then used as food by plants in essentially the same way as animals use the food they eat. It has been seen that the work of building up or elaborating takes place chiefly in the leaves. Some of the elaborated matter is used in the leaf, some at the growing points of root and shoot. Under ordinary conditions of growth, more material is constructed than is needed for the immediate nutrition of the plant. The excess is transferred to various parts of the plant to be stored for future use.

The food made by the leaves during the day is stored temporarily as starch, sometimes as sugar and oil. The starch is subsequently acted on by an enzyme called diastase, changing it into sugar which is conveyed to other parts where growth or storage is taking place. The starch is changed and transported not only in light but also in darkness. In the latter case no starch is being made to replace that which is being removed, and so we find that during the night, leaves become devoid of starch. Hence leaves picked in the early morning contain little or no starch, and those picked from a plant that has been kept in darkness for a day or two certainly contain no starch.

ENZYMES

Hydrogen peroxide is sometimes used as an antiseptic in the case of a wound. It is a simple chemical compound which, when exposed, decomposes slowly into water and oxygen, but when put on a wound it decomposes very rapidly producing froth. The bubbles in the froth contain oxygen which disinfects the wound. A substance in the wound has hastened the decomposition. That substance is an *enzyme* produced by the human body, a substance which helps a chemical change but which is unchanged after the action, that is, the substance is a catalyst. Enzymes are catalysts produced by living organisms, and every organism, plant or animal, has a great variety of enzymes.

It is possible to separate enzymes from the plants and animals which produce them, and they are still capable of accelerating their usual chemical changes. Enzymes are specialists. No enzyme is able to accelerate more than one chemical change. Those that help to turn starch into sugar are called diastases (see Chapter 2). The names of plant enzymes end in 'ase'. Proteinases help to break down proteins; cellulases, cellulose; lipases, fats. A peeled apple gradually turns brown. This change is due to an enzyme which belongs to the group called the oxidases which help to bring about the oxidation of chemical compounds.

Enzymes are protein compounds of high molecular weight. They are destroyed or rendered ineffective by being subjected to high temperature, i.e., above 60° C., and are also destroyed by exposure to light. A very small quantity of enzyme will bring about a very large amount of chemical change.

As we saw in Chapter 4, enzymes are concerned in the living processes called respiration and in the process which is in many respects the reverse of this, viz., photosynthesis. Actually the same enzymes are concerned in both processes. All chemical changes are reversible, some only to a slight extent, and enzymes can speed up either in the one direction or the other. Thus diastase in leaves turns starch into sugar or sugar into starch according to the conditions ruling in the leaves.

Some *vitamins,* substances required in small amounts for the proper nutrition of mammals, are required by the animals because they are needed to build enzymes. *Hormones* too are often necessary for enzymes. Hormones are substances which travel in the blood of an animal or in the sap of a plant and which act as chemical messengers. Organs or parts of an organism are stimulated into action by enzymes which are influenced by hormones.

PLACE OF STORAGE

Among annuals, the reserve food is stored only in the seeds to serve for the nutrition of the offspring. Among biennials (e.g., radish and carrot), and perennials, the seeds are likewise stored with food, but in such plants each growing season is marked by the storage in various organs of reserve food which serves to nourish the buds and root in the early part of the following season before the leaves have begun to perform their work. In ripe seeds, proteins supply most of the nitrogen necessary.

In seeds, starch is the commonest form of carbohydrate. It is especially plentiful in cereals, and is also found in beans and peas in considerable quantities. In seeds of linseed, rape, sunflower, and castor-oil plants the food is stored chiefly in the form of oil.

In roots the reserve food is generally starch or sugar. Both these substances are found in the parsnip and kumara. Sugar mainly is to be found in the carrot, turnip, and beet. Closely allied to starch is inulin, which is found in the roots of dandelion, chicory, and dahlia, in the tubers of the potato, and Jerusalem artichoke, and in the seeds of sunflower. It is distinguished from starch by giving a yellow or yellowish brown instead of a blue colour with iodine.

In the stems of trees and shrubs, reserve food is stored chiefly in the medullary rays and in the cortex. In modified stems, such as the potato tuber and corms, starch is of common occurrence; sugar is also found in the tuber of the Jerusalem artichoke, and often in potato tubers, particularly when they are new, or when they have started to shoot.

In the thickened leaves of many bulbs, e.g., onion, and in many fruits the stored food occurs as sugar.

The position and the nature of the food stored by plants receives much attention, for mankind depends directly or indirectly for nutrition on the substances manufactured by green plants.

GROWTH

Exercise 6.—When the root of a French bean seedling is about 1½ inches long, dry it carefully by stroking it with bits of blotting paper, and with a fine brush make on it transverse lines with Indian ink, at intervals of one-eighth inch, starting at the tip (Fig. 34). Similarly mark the stem, starting where the first pair of foliage leaves occur, proceeding downwards. Put the seedling in a thistle funnel which dips into a jar of water, and cover the seed with wet cotton wool. After a few days examine the position of the marks, both on the stem and on the root. What is your conclusion?

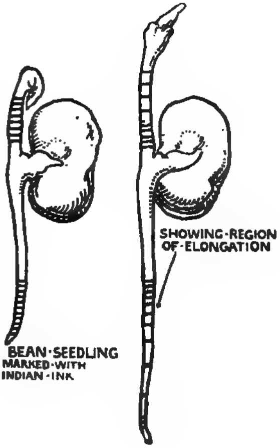

SHOWING·REGION OF·ELONGATION
BEAN·SEEDLING MARKED·WITH INDIAN·INK

FIG. 34. Growth of a bean seedling
(*From Neve's Botany*)

As we have seen, the leaf makes organic food from the raw material which it takes from the air and from the soil. Some of this food is utilised in providing energy for the vital processes, but generally the formation of organic substance is greatly in excess of the loss, i.e., there is in plants usually a constant increase in the total amount. In other words, there is growth.

It may generally be taken that the term growth implies a permanent change in the form of a living organism, and an increase in weight in the growing region. In many cases we can recognise a temporary increase in size and form without growth taking place, as for example when seeds are soaked in water, but there is no growth in the strict sense.

REGION OF GROWTH

During the early seedling stage, growth takes place in all parts of the plant, but after a time it is confined to the cylinder of cambium, which in dicotyledons, brings about growth in thickness, and to other special portions, which are known as points. These, in the case of stems and roots, are generally situated near the ends. Generally, growth proceeds slowly at first, but gradually quickens until it reaches a maximum rate, after which it slows down until, when the part acquires its permanent form, it ceases altogether. In a *root* the following regions occur:—(a) the growing point of formative tissue which is covered by the root cap, (b) the growing or elongated region, (c) the region bearing root hairs, (d) the thickening region which may bear branches (rootlets). A little behind the actual tip is the growing point, which consists of cells that are constantly dividing so as to produce new cells, most of which serve to build up the main mass of the root. Those formed towards the tip, however, add to the root cap which protects the growing point, so that as the cap is worn away on the outside by the soil in which it is growing it is being continually renewed from within. Growth is greatest not where there is the most rapid formation of cells but at some distance behind this, where increase in size of the cells chiefly takes place.

The *apex of the stem* differs considerably from that of the root, the protection of the growing point being provided for not by a cap of tissue similar to that on the root but by enfolding young leaves. Increase in length of the stems of grasses is due to the work of growing points at the base of the internodes.

The growing points of stems and roots do not elongate in straight lines, but travel in a spiral line in their upward or downward growth. This is due to the fact that the side on which there is most rapid growth varies from time to time, and the tip always bends away from the side on which most rapid growth occurs. By means of such spiral movements roots are more easily able to travel through the soil. In stems the movement is well seen and is of conspicuous utility in plants which climb by twining stems or by tendrils.

CONDITIONS WHICH INFLUENCE GROWTH

From our previous study of the functions of roots and stems we are able to summarise the conditions necessary for healthy growth as—

1. A suitable *temperature*—the point at which growth goes on most rapidly is about 28° C. for most common farm and garden plants. Extremes either of heat or of cold are often the cause of serious damage to living plants. The amount of water which a plant contains greatly influences its power of withstanding severe heat or severe cold. Dry seeds may withstand a dry heat of 80° C. for an hour, whereas soaked seeds may be killed by an exposure to a temperature of 52° C. for 10 to 30 minutes.

Again, well-matured parts of plants, which contain comparatively little water, do not suffer so much injury from frosts as do immature succulent parts such as opening flower and fruit buds and young seedlings. The germinating capacity of maize is likely to be injured if the cobs are exposed to severe frosts in the autumn. This danger is minimised if the grain is dead ripe, and therefore drier than in early stages. At or about freezing point, death is somewhat similar to death by drying, for water is allowed to move out of the living cells into the neighbouring intercellular spaces, where it freezes into ice. The formation of ice is not always fatal for, if thawing is gradual the water is re-absorbed by the cells, but if thawing is rapid the water is not re-absorbed, and death of the cells takes place. This explains why, when frosts are liable to be experienced, tender crops such as early potatoes or tomatoes should be grown in a position which does not receive the early morning sun, as a position shaded in the morning ensures a gradual thawing.

2. *Light* is not necessary for all phases of growth, e.g., the development of stems goes on in darkness as well as in light, and

the potato tuber commonly produces shoots in the darkness of sack or cellar. Such growth is usually rapid, with long internodes and lacking chlorophyll. It is referred to as etiolated.

For healthy growth of the whole green plant, light is absolutely essential, for we have already seen that photosynthesis occurs only in light, and further that photosynthesis is an essential activity in the nutrition of green plants. Plants grown in total darkness will not flower.

Flowering period is greatly affected by the relative lengths of daylight and darkness. Thus some plants will not flower unless they are exposed to a light day of more than 14 hours. Such plants are called *long-day plants*. There are other plants which will flower only in the short days of the autumn, winter or early spring, no matter when the plants are sown. These are *short-day plants*. By using artificial light to increase the day length it has been found that long-day plants can be made to flower in the winter. Similarly by placing dark covers over short-day plants, they can be made to flower in the summer. To put it another way, many plants flower according to the calendar, for the length of daylight on any given date at a given latitude is largely independent of the weather.

Examples of long-day plants are:—wheat, barley, radish, lettuce and beet, and examples of short-day plants are:—French bean and chrysanthemum.

TO SHOW THE EFFECT OF LIGHT ON THE DIRECTION OF GROWTH

Exercise 7.—Wrap brown paper round a wide glass jar, but leave a perpendicular slit about one-eighth inch wide so as to have light entering from one direction only. Place about an inch of water in the jar to keep the air moist. Then from a piece of cardboard fitting evenly over the mouth of the jar suspend by cotton a vigorous seedling which has made a growth of about two inches, and note the direction of subsequent growth for a period of several days.

Exercise 8.—Roll a piece of blotting paper and place it in a glass jar so that it is in close contact with the sides. Take 4 germinated broad bean seeds from which the radicle has just emerged, and slip them between the glass and the blotting paper. Arrange these so that the radicles point downwards, upwards, horizontally to the right and to the left in different seeds. Then fill up the centre of the jar with well moistened sawdust. Observe daily, and make diagrams of the development of the seedlings, noting particularly the direction of growth of root and shoot.

Exercise 9.—Grow seeds in sawdust or loose soil in a box with a bottom of wire gauze. Tilt the box up at one end. The roots grow through the gauze into the dry air, but soon curve backwards. Compare this result with another set of seeds grown as follows:—Take a jar containing water, tie over it some muslin on which is placed damp material, e.g., sawdust. In this place some soaked seeds, and invert a beaker or other suitable vessel over the whole to check evaporation. In this case the roots do not curve back, but continue their growth through the moist air.

Exercise 10.—Fill a large filter funnel with moist sawdust. Sow some seeds near the top of the funnel and close to the glass, and place various hard objects directly below them at a distance of about an inch. Note when the roots strike these, whether they diverge from their course, and if so, whether they continue in the altered direction later, or return to the original direction of growth. Small stones, marbles, etc., serve as suitable obstacles.

Exercise 11.—In the daytime cover a white clover plant with a tin pneumatic trough or other opaque vessel, so that all light is shut out. After a few hours compare the position of the leaves of the darkened plant with that of the leaves of the exposed plants, i.e., compare the 'night' and the 'day' positions.

Exercise 12.—On a bright day exclude the light from some well-opened heads of daisies or dandelions. Note whether the heads have closed after being about two hours in darkness. What happens when they are again given a bright situation?

3. *Water* is necessary for growth, serving both as a food material and a means of transport of raw materials and the foods elaborated from them.

A crop plant contains about 80 per cent water but this is only a small proportion of the amount taken from the soil. As we saw in Chapter 5 most of the water a plant takes up is lost by transpiration, i.e., by evaporation mainly through the stomata in the leaves.

The amount of water transpired during the formation of a definite weight of dry matter varies with the kind of crop, the temperature, and the food and water supply, but normally any of the cultivated crops transpires from 300 to 500 tons of water for each ton of dry matter formed. The significance of these figures becomes obvious when individual cases are taken, e.g., Hellriegel found that wheat uses about 400 tons of water in forming 1 ton of dry matter. A crop yielding 40 bushels per acre produces 3 tons of dry matter, and therefore requires from one acre during the growing period 1200 tons of moisture, which is equivalent to approximately 12 inches of rainfall. Again, it has been found that to obtain 5 tons per acre of clover hay at least 17.7 inches of rainfall must be taken from the soil by the crop. When we remember that a considerable portion of the rainfall is lost to crops by evaporation and by surface drainage, it is obvious that crop yields must frequently suffer through inadequate moisture supply.

Where there is a marked deficiency of soil water during the summer, special measures should be taken by farmers.

(1) Prominent use should be made of deep-rooting crops like lucerne, especially on light soils. This is because such crops are able to draw water from a larger volume of soil and to a greater depth than other crops.

(2) Where wheat can be grown, it is likely to be more successful if sown in May rather than in September because the May sown crop is well developed and deeply rooted by the time transpiration begins to exceed rainfall.

(3) Because much less water is lost by evaporation from a bare soil than from a cropped soil, especially if the bare soil has a fine surface layer, fallowing the land during the summer helps to conserve the soil water for autumn-sown crops and pasture.

(4) Given a good water supply from river, well or race, then irrigation of pastures and crops may prove a payable proposition. (See Chapters 10 and 18.)

The amount of water in the soil has a marked effect on the crops. On moist soils the plants usually have larger wider leaves and are of greater size than those on drier soils. Further, an abundant supply of moisture causes ripening to be delayed.

4. *Oxygen* is necessary, as was discussed in respiration.

5. *Food* materials are needed to supply the substance for respiration, and for the construction of the growing parts. (See Chapter 5.)

6. *Hormones* control growth. All organisms contain these substances which act as chemical messengers travelling to the parts or organs and influencing their action.

Exercise 13.—Germinate in the dark seeds of wheat, oats, or barley until each seed produces its first leaf-sheath or coleoptile, a tender, hollow spike enclosing, rolled up, the first true leaves.

(a) In a darkroom expose a seedling to sunlight for less then a second, and then notice that the coleoptile curves towards the direction in which the light showed.

(b) Place a seedling on its side for a few minutes and then return it to the vertical position. Notice that, after a while, the coleoptile curves to one side, the direction of the vertical if it had still been lying down.

(c) Put a tiny cut in one side of the shoot of another seedling and notice which way it curves.

What takes place in the coleoptile is due to hormones. Such changes go on, but less quickly and sensitively, in all growing shoots, e.g., a pot plant near a window grows towards the light, a crop such as oats beaten down by the weather (lodged) grows upright again.

These growth changes are due to the action of growth hormones. Like enzymes, growth hormones can be extracted, in small quantities, from growing shoots. Relatively large amounts, however, are obtained from yeast, from special cultures of fungi and bacteria, and from animal urine, and they are obtained also synthetically. The kinds and amounts of hormones found in urine are closely related to the kinds and amounts of the food eaten by the animal.

Growth hormones or auxins have other important effects, several of which are related to farming and gardening. There is first the effect on *the development of buds*. The bud at the end of a rapidly growing shoot produces more hormone than it needs for its own growth. The excess hormone flows back down the stem preventing growth in the lower buds. Why the hormone should promote the growth at the tip and inhibit it elsewhere is not known. When a tree is pruned (see Chapter 25), the tips of certain shoots are cut off. This means that the downward flow of hormone in those shoots is stopped and the buds just below the cut sprout and grow into side shoots. In their turn the new terminal buds produce hormone which prevents buds further down from developing.

Then there is the control by hormone of the *formation of roots* on shoots. This is important in propagating by means of cuttings (see Chapter 22). Cuttings have hormones developed from the buds and these hormones travel to the base to produce roots.

There are many kinds of plants, however, which are hard to root by cuttings. If the lower ends of such cuttings are dipped into a solution of artificial hormone of low concentration, then roots can often be induced to form. Too strong a solution may prevent rooting and may produce other bad effects.

Flowering too is affected by hormone (see Chapter 7). It seems that the same hormone at different concentrations has different effects upon the various parts of a plant. This is shown diagrammatically in Fig. 35 where the varying effect of the same hormone at different concentrations on roots, buds, stems and flowers is shown.

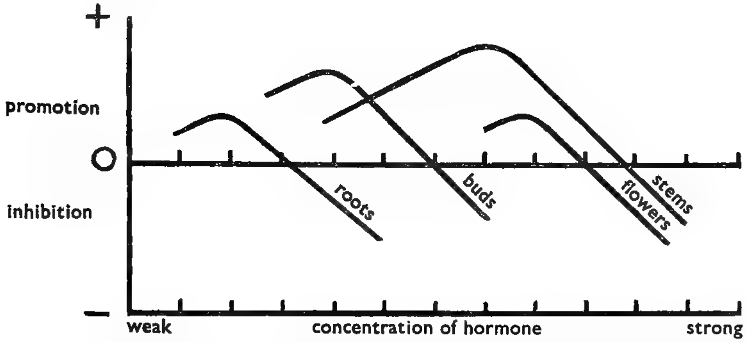


FIG. 35. Diagram to show the varying effect of the same hormone at different concentrations on plant parts

(*After Leopold and Thimann and modified from 'Science News*', 18 Nov. 1950, p. 37)

Another important effect of hormones on plant growth is in *preventing fruit drop*. Towards the end of a growing season in the base of a fruit stalk (and a leaf stalk too) there develops across the stalk a corky layer, the abscission layer, which weakens the stalk and causes the fruit (or the leaf) to blow off easily. Some fruits, especially some varieties of apple, tend to fall before they are ripe, or, if ripe, before they can be picked. If apple trees are sprayed with the appropriate hormone solution a short time before fruit drop may be expected, then the formation of the abscission layer is delayed for two or three weeks giving time for the ripening to proceed to the correct stage for picking.

The effect of artificial hormones as *growth inhibitions* is also useful in preventing stored potatoes and stored root crops from sprouting. There are other synthetic hormones which so upset plant activity that they are useful as weed-killers. (See Chapter 26.) Also by the use of hormones plants may be induced to produce fruit without having to be pollinated, and the fruit is therefore seedless. (See Chapter 7.)

Exercise 14.—Taking a few unsprouted potato tubers rub half of them all over with anti-sprout hormone, leaving the other half untreated. Place the two lots of tubers in a warm, lighted place and compare the progress of the two lots over the next few weeks.

Movements of Plants

Many parts of plants, but particularly growing organs, are irritable, that is, they make responses to external conditions, such responses being commonly in the nature of a movement which brings the plant 'into touch' with its surroundings, or, in other words, makes for harmony between the plant and its environment. The chief causes which induce movements in plant members are:—

1. *Light.*—Shoots generally grow towards, roots away from, the light. A good example is seen in a window plant. Unless the plant is regularly turned around the stem bends over towards the light. By such movements the stems are enabled so to place the leaves, that photosynthesis is most favourably carried on, and the roots are aided in penetrating the soil.

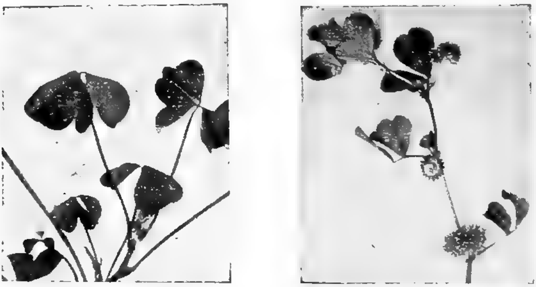


Fig. 36. Leaf movements: *Left*, Showing downward closing movement of leaves of oxalis. *Right*, Showing upward closing movement of leaves of toothed medick (*After V. W. Jackson*)

2. *Gravity.*—All bodies on the earth are attracted to its centre by a force which is spoken of as the force of gravity. This force acts on plants: most primary stems grow vertically upward against the force, while primary roots grow downward. When the seedling is displaced into a horizontal position it is found that curvature takes place at the growing regions of stem and root, so that the former turns upward, the latter downward. Certain stems are exceptions, e.g., runners and rhizomes; they grow naturally in a horizontal position. Leaves behave similarly, and thereby place themselves at right angles to the direction of light. Lateral roots are scarcely influenced by gravity, growing outwards from the parent plant. The advantage is obvious.

3. *Moisture*.—As roots grow through the soil they bend towards the parts which are dampest, the presence of water being a more powerful stimulus than gravity. This, of course, is useful for the roots, but they will not penetrate regions saturated with moisture. They are, however, frequently attracted by water into drains, water courses, and wells.

4. *Contact* with a foreign body often causes movement which is best exemplified in roots and tendrils. When a growing root encounters some obstacle, such as a stone, it turns away, because of the portion near the tip being sensitive. By this means roots pass objects obstructing their normal path. Tendrils and certain twining stems, e.g., dodder, on touching a foreign body tend to curve towards it. The bending occurs because in roots growth is most rapid on the side in contact with the foreign body; in stems and tendrils on the side not in contact.

5. *Variations in Temperature* cause movement in certain flowers, e.g., crocus and tulip, which close when brought to a cool place and *vice versa*. The closing of the flowers greatly protects their organs against frost.

The leaflets of clovers and oxalis fold at night and open in the morning. Such movements, which are sometimes spoken of as the 'sleep of plants', are caused by variation in light and temperature and protect the leaves against injury by cold.

READING

Agricultural Botany (Chapter 6),
Yeates and Campbell

**New Biology*,
8 April 1950 (Enzymes)

**Science News*,
1 June 1946 (Hormones)

**New Biology*,
5 Sept. 1948 (Hormones)

* Mainly for the teacher

FILMS

(The National Film Library)
'Plant Growth'

7

Flower and Fruit

THE FLOWER may be defined as that part of the plant which is specially adapted for the production of seed in order to reproduce itself, and so keep up a succession of its kind. Many, but not all, flowers contain brightly coloured parts, e.g., the flowers of cereals and grasses generally possess no gay colouration. Again it must be remembered that all brightly-coloured structures are not parts of true flowers. For instance, what are popularly considered flowers of bougainvillea are really coloured leaves surrounding inconspicuous flowers. Again, the seeds produced by flowers are not the only means whereby plants are propagated: stems, and occasionally roots and leaves may be utilised to obtain new individuals, e.g., cuttings, runners, bulbs, corms. But *flowers are the only organs whose sole and special function is that of reproduction.*

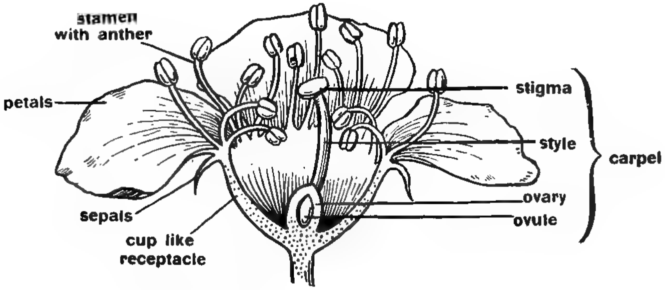


FIG. 37. Flower of plum

PARTS OF A FLOWER (Figs. 37 to 40).

If we examine any of the following flowers: peach, apple, buttercup, cabbage, potato, radish and bean, we find an upper and lower part. The latter in most cases is green and is the calyx. It consists of a number of parts called *sepals*, which may be separate from one another, e.g., buttercup, or joined together as a cup or tube with the upper edge notched or divided into lobes, e.g., peach and apple. Above the calyx is the structure called the *corolla,* which is often brightly coloured. It consists of parts called *petals,* which vary much in shape, size, and colour in different kinds of flowers. Sometimes the petals are united, e.g., potato, sometimes they are separate from one another, e.g., cabbage. Inside the corolla is the *androecium,* made up of structures called *stamens.* These consist of rod-like stalks called *filaments,* which have at their tips the knob-like *anthers,* which contain a fine, floury, yellow dust called *pollen.* The number of stamens varies greatly in different kinds of flowers: they are sometimes separate, e.g., apple, and sometimes all of them are united, e.g., gorse, clovers, beans.

In the centre of the flower is the *gynaeceum,* composed of *carpels,* each of which generally consists of ovary, style, and stigma. The *ovary* is the swollen hollow basal part: it contains

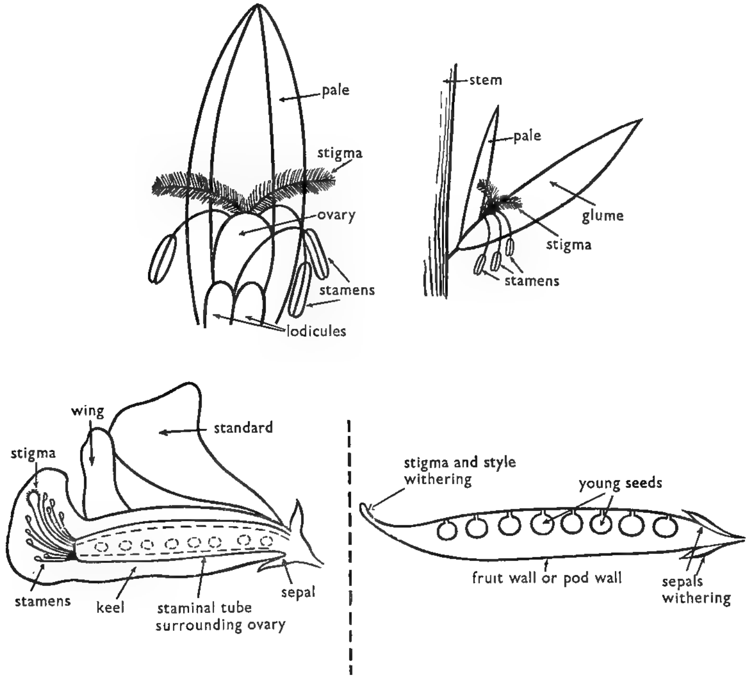


FIG. 38. *Top*: Diagrams of a typical grass floret; *Bottom left*: A pea flower or floret; *Right*: A young pea pod

small rounded bodies termed *ovules,* which under suitable conditions develop into seeds. The *style* is the slender stem arising from the ovary. At the apex of the style is a slight enlargement called the *stigma.* Often the style is missing, the stigma being placed directly on the upper part of the ovary. The gynaeceum sometimes consists of separate carpels, e.g., buttercup, but more often they are united more or less completely, with the result that several carpels form one common ovary. In the case of united carpels there are often partitions formed by the folding of the united parts so that the common ovary is divided into several cavities.

Although the flower is in many respects different from other parts of the plant *it is a simple shoot modified for the special purpose of reproduction.* The position of the flower shows that it is a special form of shoot, for flowers are found at the apex of stems or in the axils of leaves, just as are shoots bearing foliage leaves. The parts of a flower, e.g., sepals and petals, which are called floral leaves, exhibit similarities in structure and veining, to foliage leaves. The upper part of the stalk to which the parts of the flower are attached is called the *receptacle.* It is generally soft and somewhat swollen.

Effect of Removing Anthers

Exercise 1.—Remove the anthers from a flower which has not opened, e.g., peach, bean, wallflower, gladiolus. Then tie a small bag of cellophane or of fine muslin over the flower to prevent the pollen from another flower reaching the one from which the anthers have been removed. The anthers must be carefully removed so that no pollen is shed and the other organs are not damaged. Note whether any seeds are formed. Remove the anthers from several other flowers but do not cover these, and note whether any of these produce seeds.

Effect of Removing the Stigma

Exercise 2.—Carefully cut away the stigma from young unopened flowers, and note whether this ultimately affects seed formation.

INFLORESCENCE

Most plants produce flowers not singly but in groups or heads called *inflorescences,* e.g., gladiolus, clover, wheat, daisy. Each flower in an inflorescence is called a *floret* which is essentially similar in structure to a flower borne singly. For the structure of florets in some plants of agricultural importance, see the diagrams, Figs. 38 and 39.

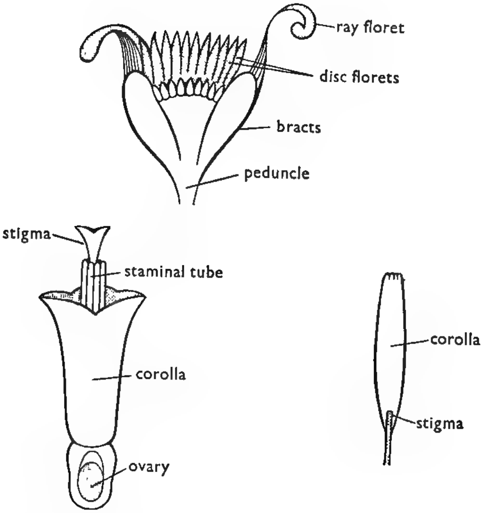


FIG. 39. Florets in an inflorescence of a daisy

Exercise 3.—In the spring note the grasses which flower first. Flowering in a grass can be readily seen by the stamens hanging from the head. Take one of the flowering heads and with tweezers and mounted needles separate the head into the pieces called spikelets and then separate the florets from the spikelets. Examine a floret under a magnifying glass and make a sketch of it.

Exercise 4.—Taking a flower of a pea or a bean remove the petals noting the largest called the standard, the boat-shaped keel, and the two smallest petals, the wings. Make sketches of each of these petals. Carefully slit the staminal tube lengthwise to reveal the ovary underneath. Make a sketch of the flower with the petals removed, naming each part.

Exercise 5.—From a plant of the daisy family with a large 'flower', really an inflorescence, (e.g. sunflower, ox-eye daisy, chicory, ragwort) select a full-blown 'flower'. Note its disc-shaped, compact central portion and a less regular rim, all held together by green or brown coloured bracts. With a pair of tweezers remove some of the bracts followed by some of the parts of the rim or ray and of the disc. Note that the rim or ray and the disc are made up of many florets, the outer ray florets being irregular in shape and lacking stamens and the inner disc florets being regular. There are no sepals.

ESSENTIAL PARTS

The androecium and gynaeceum are the only parts of the flower directly concerned in and necessary for seed production, and the whole design of the plant is to enable these to perform their work successfully. Hence the androecium and gynaeceum are spoken of as the essential organs; the other parts of flowers provide protection to the essential parts or attract insects to these parts.

FUNCTIONS OF THE PARTS OF FLOWERS

By watching flowers at intervals for some weeks from the date of opening, it is seen that the gynaecium develops into a body which contains a seed or seeds from which new plants will be produced.

It is found that ripe seeds are not formed unless *pollination* occurs, i.e., unless pollen is deposited upon the stigma, and this is followed by fertilisation. When the stigma receives pollen from the anthers of the same flower, or from any flower on the same plant, we have an instance of *self-pollination*: when, as often happens, the pollen comes from a flower on another plant, we have a case of *cross-pollination*.

Under suitable conditions pollen placed on a stigma emits a thin tube-like structure, which grows down through the style and ovary wall into the ovule. (See Fig. 40.)

FERTILISATION

Pollen will not germinate on a stigma unless the stigma is ready or *receptive*, when it usually has a sticky, sugary solution on its surface. The pollen tube in growing down the style may have to grow only an inch or so and may take only a few hours or days. In plants like maize, however, (see Figs. 92 and 93, pp. 332 and 333) it has to travel a distance greater than a foot and in some trees like oak and beech it has not far to grow but takes many months. When the pollen tube, feeding on the style, reaches the ovule, it penetrates the *embryo sac* into which it sheds its two male nuclei. One of these male nuclei is the male gamete or sperm which unites with the female gamete or egg nucleus in the embryo sac to form a fertilised egg nucleus called the *zygote*. This fusion, or intimate combination, of a male gamete from a pollen grain with a female gamete from an ovule is called *fertilisation*. Briefly this may be shown thus:—

Sperm + egg = zygote (Fertilisation).

The other male nucleus of the pollen tube unites with another nucleus in the embryo sac to form a cell which divides and redivides many times to form a food reserve called the *endosperm*.

By repeated division of the zygote cell an *embryo plant* is formed consisting of a root, and a shoot with one or two cotyledons depending on whether the plant is a monocotyledon or a dicotyledon. During this division some or all of the endosperm food may be used up. With plants like peas and beans the embryo uses up all the endosperm but with plants like wheat and maize most of the endosperm remains.

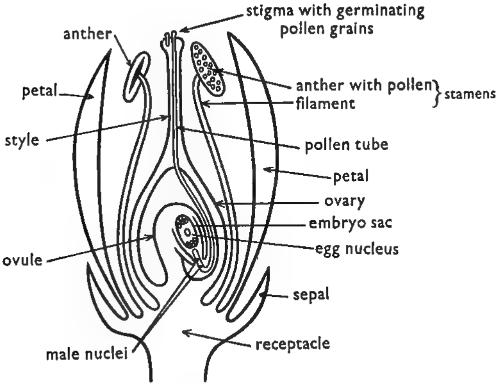


FIG. 40. Diagram of a flower showing fertilisation

Exercise 6.—Get as many different kinds of flowers with ripe pollen as possible. Examine the pollen grains under a microscope.

Exercise 7.—Put some ripe pollen into 10 per cent cane sugar solution in a watch glass, cover with another watch glass, and leave for a few hours. Several watch glasses may be used with one kind of pollen in each. Then using a microscope look for pollen tubes in the solution. If a receptive stigma from the same kind of flower as that from which the pollen grains were obtained is placed in the solution with the germinating pollen grains, then it may be possible to see some of the pollen tubes growing towards the stigma.

THE NARROW BRIDGE BETWEEN ONE GENERATION AND THE NEXT

When one generation of plants gives rise to another by fertilisation, there is only a very tiny connexion between one generation and the next. That connexion or bridge is the one cell called the zygote. As it is formed by the union of male and female gametes from male and female parents respectively, it is a double cell. When this double cell zygote divides many times to form the cells of the embryo, all the cells of the embryo, and later of the whole plant, have this double inheritance, a double lot of genes,* half from each parent. When the new generation of plants in their turn become mature and produce male and female gametes, each gamete receives from its parent only a single lot of genes, i.e., half the amount in the cells of its parent. Thus, when the zygote of the new generation is formed two singles make a double so that the double lot of genes is restored.

Although hundreds of ripe pollen grains often fall on a receptive stigma, and although several germinate and grow down the style, only one pollen tube can penetrate any one ovule. It is largely a matter of chance which pollen grain reaches a particular ovule and fertilises it. So in inheritance fertilisation is at random.

This matter of inheritance is important in plant improvement by breeding which we shall discuss later in this chapter.

DEVELOPMENT OF SEED AND FRUIT

When fertilisation has occurred and the embryo and endosperm are developing inside the ovule, the other parts of the flower are changing too. The petals, stamens, stigma, style, and perhaps the sepals, wither and fall off; the walls of the ovule expand and become tough to house and protect the embryo inside, the micropyle remaining as an opening, and the whole developed ovule becomes a *seed;* the ovary enlarges and forms a *fruit* surrounding and protecting the seed and providing for the dispersal of the seed. (See later.) Some fruits have their fleshy portion developed not from the ovary but from the upper end of the flower stalk called the receptacle, e.g., apple, strawberry.

Some plants produce fruits without fertilisation and these fruits of course are seedless, e.g., navel orange, seedless grapefruit, banana, and some varieties of pear and grape.

The fruit then develops mainly from the ovary as the result of fertilisation, whereas the seed develops from the ovule alone. There is considerable looseness in popular language in the use of the words fruit and seed. For instance, the 'seeds' of cereals

---

* Genes are chemical entities (nucleoproteins) and are the factors or carriers of attributes both physical and mental. They are invisible, except as a chain (chromosome), and their number is not known but probably runs into many thousands.

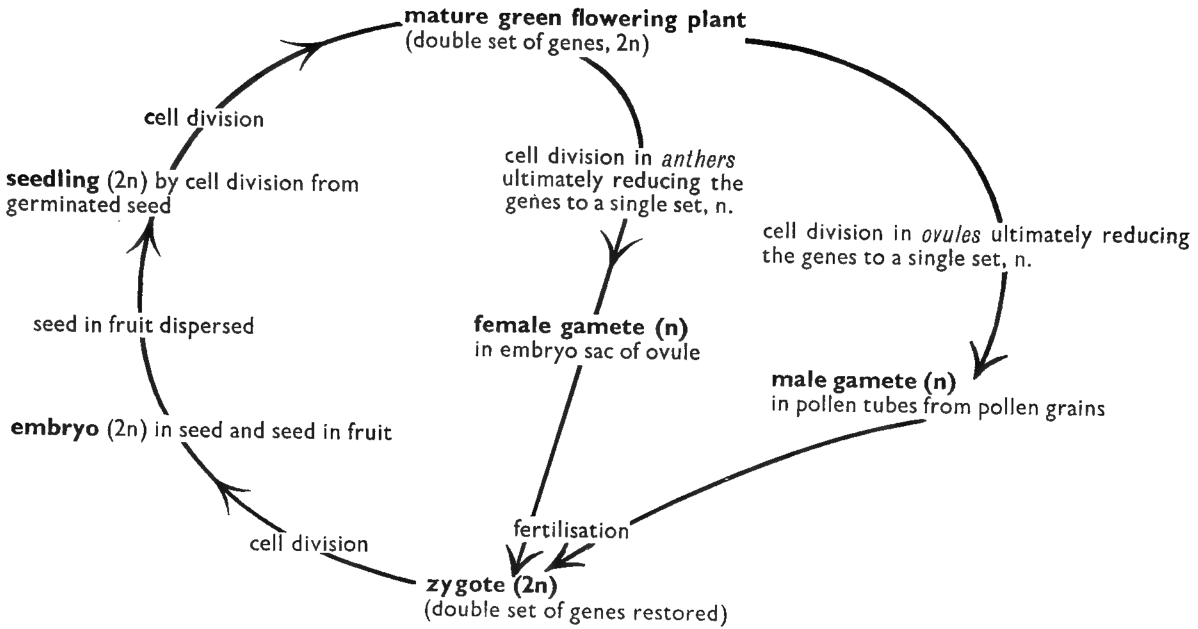

mature green flowering plant
(double set of genes, 2n)
cell division in *anthers* ultimately reducing the genes to a single set, n.
cell division in *ovules* ultimately reducing the genes to a single set, n.
female gamete (n)
in embryo sac of ovule
male gamete (n)
in pollen tubes from pollen grains
fertilisation
zygote (2n)
(double set of genes restored)
cell division
embryo (2n) in seed and seed in fruit
seed in fruit dispersed
seedling (2n) by cell division from germinated seed
cell division

FIG. 41. Life cycle of a flowering plant

and most grasses are really fruits: they consist of seeds, to the coats of which the fruit cases are fused; the 'seeds' of potatoes are really swollen stems (tubers), and the 'seeds' of mangels are clusters of fruits containing seeds embedded in woody material. Again, the cucumber and marrow which are popularly classed as vegetables, are fruits in the botanical sense, as also are the tomato, the pod of peas and beans, and the 'seed' of the dandelion with its parachute device of silky hairs. Fruits vary a great deal in character; they may be dry as in the pea and cabbage, or fleshy as in the peach and apple. The functions of the fruit are to provide for the protection and distribution of the seeds which they contain. The development of the fruit may be checked by insects and by diseases. As most crops reproduce by seed, and as many crops are grown specially for their fruit or seed, it becomes necessary to ensure healthy development of the fruit. Hence it is often necessary to spray to control insects and disease. Overcrowding of crops must also be avoided, for the fruits need light and air for their healthy development. Herein lies one of the main reasons for the pruning of fruit trees, and the thinning of fruit.

Exercise 8.—Cover several young unopened flowers of various sorts with fine muslin bags, and note whether seeds are formed in any or all instances, e.g., peach, apple, bean, clover, wallflower. Compare with similar flowers which have been left uncovered. What inferences are to be drawn?

Exercise 9.—Examine plants of marrows, melons, and squashes, for two types of flowers. Cover with a thin muslin bag an unopened flower which possesses a tiny marrow or melon, and note whether the latter develops. Compare with uncovered but otherwise similar flowers.

Exercise 10.—Distinguish the 'tassel' and the 'ear' of a maize plant. Cover an unopened ear with a muslin bag, and compare the result with that of ears which are not covered.

SELF-FERTILISATION AND CROSS-FERTILISATION

We speak of self-fertilisation and cross-fertilisation according to the way in which pollination occurs. In most cross-fertilised plants self-fertilisation results in weakened vitality of the progeny; so plants possess various devices, which will be discussed later, which ensure that the pollen is carried from flower to flower, e. g., lucerne and clover. In self-fertilised plants, however, the floral structure or mechanism is such that the pollen is usually forced to reach the stigma in the same flower, e.g., bean, pea, tomato, lettuce, and there is no reduction in vigour.

PROTECTION OF POLLEN

Pollen grains, if moistened, are not well able to withstand extremes of temperature, and in most cases pollen grains which have been wetted and dried are unable to bring about fertilisation. Hence flowers have various structures and mechanisms which bring about the *protection of pollen* in various ways, the commonest being:—

(a) Closing the flowers or flower heads at night to avoid injury by dew or by cold, e.g., daisy family, oxalis, scarlet pimpernel, crocus.

(b) The drooping or horizontal position of flowers lessens the danger of rain entering the flower, e.g., violet, daffodil, bluebell and winter sweet (*Chimonanthus*).

(c) In some cases a waxy or spiny covering prevents the pollen grains from becoming wet.

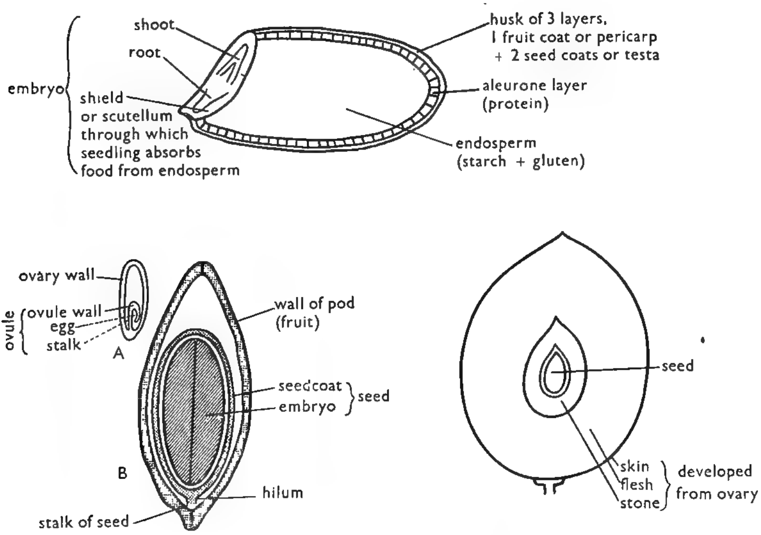


FIG. 42. *Top*: Section through a wheat grain. *Left* A: Transverse section of ovary of pea. B: Transverse section of the fruit (pod) showing the changes as the fruit develops from the ovary. The ovary wall has developed into the pod and the ovule has become the seed. The seed coat comes from the ovule wall, the embryo from the fertilised egg. The hilum is a weak place where the seed will break away from the pod. *Right*: Development of a stone fruit

(Modified from Yeates and Campbell: *Agricultural Botany*, p. 112)

HOW POLLEN IS CARRIED

Pollen, in itself, has no power of movement. If the anthers are above the stigma, pollen may fall on the latter resulting in self-pollination. But often, as in cross-pollination, the pollen is carried by wind, e.g., grasses, or by insects, e.g., clover, sometimes by water, e.g., water-lilies, and sometimes by birds, e.g., N.Z. flax.

WIND-POLLINATED AND INSECT-POLLINATED FLOWERS

There are marked differences in structure between wind-pollinated flowers and insect-pollinated flowers. Such differences have developed during the evolution of flowering plants, and the structures in each case have survived because the plants possessing them had advantages over other plants not possessing them in the struggle for existence.

1. In wind-pollinated flowers there are not the bright conspicuous colours found in those visited by insects.

2. Wind-pollinated flowers are devoid of scent and nectar, both of which often occur in flowers which depend on insects for pollination.

3. Many of the pollen grains carried by the wind do not strike a stigma. Hence in wind-pollination a much greater amount of pollen is produced than in insect-pollination. Further, the pollen to be carried by the wind is dry and dusty, while that to be borne by insects is more or less granular.

4. In wind-pollinated flowers the stigmas are usually large and produced in prominent positions by the presence of long styles, whereas where insect-pollination occurs the stigmas are relatively small, and are situated within the flower.

5. In wind-pollinated flowers the anthers are carried on long dangling filaments, but when insects transport the pollen the stamens are relatively small and included within the flower.

Exercise 11.—Compare the wind-pollinated flowers such as maize, grasses, plantain, dock, sorrel, willow, pines, with insect-pollinated flowers such as clovers, lucerne, daisies, apple, and draw up a comparison in tabulated form.

Exercise 12.—Examine the following flowers:—buttercup, poppy, cabbage, violet, primrose, carnation, lucerne, gorse, clover, strawberry, apple, pear, dandelion, thistle, carrot.

Note whether—

1. Stigmas or anthers ripen the earlier.
2. Insects are attracted by stores of nectar, and if so, whether there are any ways of guiding the visitors to the nectar, e.g., ridges and coloured stripes.
3. Sense of colour draws the attention of the insects.
4. There is any structure specially suited for the alighting of the insects.

EFFECTS AND CAUSES OF NON-FERTILISATION

In the case of practically all crops of economic importance if fertilisation does not take place, fruit either will not form at all, or if it does form it will not mature. The most common causes of non-fertilisation are:—

1. Absence of suitable insects. The more or less complete failure of fruit crops, most of which require cross-pollination, is frequently due to this cause, and may be largely avoided by locating bees in or near the orchard during flowering time at least. This is specially important because the percentage of sugar in the nectar of many kinds of fruit trees is low compared with that from other trees flowering at the same time. So, unless bees are housed right in an orchard, they will be attracted by the better nectar of other trees.

Red clover is also of interest in this connexion for the crop rarely seeded in New Zealand till the humble bee was imported. Again, as plants in greenhouses are not usually visited by insects, hand-pollination may be necessary, e.g., cucumbers.

2. Injury to the pollen or stigma by frost, rain, or hail. Occasionally serious damage results to wheat and fruit crops by late frosts occurring just at the time of fertilisation.

3. Damp weather unfavourable to the working of insects prevents pollination. Damp still weather will also prevent the pollen being conveyed by the wind.

4. Absence of suitable pollen-bearing flowers. This is of particular application to orcharding. Many varieties of pear, apple, plum and cherry are described as *self-sterile*. Flowers of such varieties are not readily fertilised with their own pollen, or with that from another tree of the same variety. In ignorance of this, large blocks of a self-sterile variety are sometimes planted, and of course remain unfruitful till other varieties which flower at

the same time and produce suitable pollen have been planted near or among them. Again, the flowers of certain varieties of strawberries bear few or no stamens so that there is not enough pollen to fertilise all the blossoms. Alongside such varieties it is desirable to plant other varieties which produce many stamens, and thereby provide the pollen necessary for fertilisation.

DEVICES TO SECURE CROSS-POLLINATION

The following are the chief devices by which nature tends to make sure of cross-pollination:—

1. The androecium and gynaeceum are placed in different flowers on the same plant. The lower part of a marrow, pumpkin, or cucumber flower consists of a swollen structure which grows into the edible marrow or cucumber. No stamens will be found in such cases, but other flowers, which possess only stamens, produce the pollen. Another example is the maize, in which the pollen is produced in the 'tassel' at the top of the plant, and the gynaeceum occurs as the ear, the 'silk' being the styles and stigmas (Figs. 92 and 93). Other examples are the pine and hazel.

2. In other cases the androecium and gynaeceum are borne on separate plants, e.g., willow, hop, clematis, and Chinese gooseberry in which case there are male and female plants.

3. In many flowers that have both androecium and gynaeceum, cross-pollination is enforced by the stigma and pollen of the one flower or plant ripening at different times. The ripe pollen is shed before the stigma is ready to receive it in the case of sunflower, daisy, carrot, mint, maize, and most members of the different families to which these plants belong. The stigma ripens first and receives pollen from an older flower in ribgrass, meadow foxtail, sweet vernal, hawthorn, apple, pear.

4. In some cases the pollen has no effect upon ovules produced in the same flower, e.g., some species of passion-flower, lobelia.

5. In certain cases in which the androecium and gynaeceum ripen at the same time, the position of the parts is such that the transference of pollen from a stamen to the stigma of the same flower is uncertain or impossible. In such cases there are

necessarily special devices favouring cross-pollination by wind or by insects. Such devices occur in the violet, primrose, salvia, mint, and iris.

Some plants produce viable seeds without normal fertilisation, e.g., hawkweeds, dandelions.

The Fruit and Seed

Exercise 13.—Watch suitable flowers, e.g., peach, apple, bean, wallflower, cabbage, oats, wheat, sunflower, from the opening of the flower to the ripening of the fruit, and note what becomes of the various floral parts in each case.

Exercise 14.—Examine the fruits of the main farm crop and common weeds and note:—(a) whether they are dry or succulent, (b) whether they split open to allow the seeds to escape or not, (c) whether the seed-box consists of one or more cavities, and how many seeds it contains.

Seed Dispersal

If seeds are well distributed, the seedlings are provided with soil that has not been exhausted of its supply of food materials, and overcrowding and consequent shading are also avoided.

Dispersal is effected—

1. By *wind.* Some seeds are very light, others are smooth, and so are easily blown about or rolled along the ground by the wind. More often the seed or fruit is provided with a large and light attachment which renders it buoyant (Fig. 43). For instance, the fruits of many members of the daisy family, such as thistles and dandelion, possess a tuft of long fine hairs, by means of which even in moderate breezes they are carried long distances before they drop to the ground.

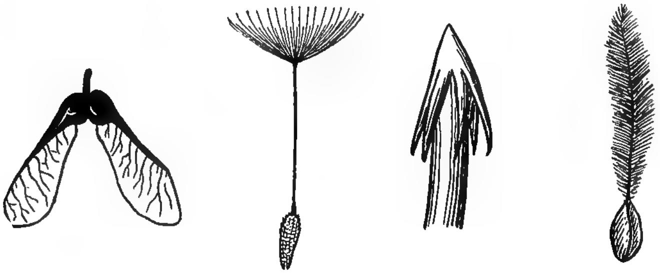


Fig. 43. Dispersal of seeds: From *left*, Winged fruit of sycamore; dandelion fruit; barbed spine (magnified) of *Acaena*; feathery fruit of clematis

The clematis, poplar, willow, and willow-herb (*Epilobium*) ensure distribution of their seeds by a similar device.

The sycamore, pine, and ash are examples of seeds which are wind-borne, because of the wing-like structures with which they are provided (Fig. 43).

Many grasses are spread because of the light bracts which surround the 'seeds'.

2. By *animals*, which often carry seed or fruit clinging to their coats. This is the case with piripiri (*Acaena*) (Fig. 43), cleavers, Bathurst burr, docks, burr clover, and carrot, all of which are characterised by barbed or rough or spiny coverings.

In other cases fruits of a succulent character are eaten by birds and other animals, and the seeds pass through the animals' bodies and still retain their power of germination, e.g., cherry, berries, hawthorn, inkweed (*Phytolacca*).

3. The fruit may be eaten with the leaves of the plant by a grazing animal, as with clovers, the seed passing through the animal unharmed.

4. In some comparatively few cases the fruit, when ripe, bursts open with violence, and thereby scatters the seed, e.g., gorse, cranesbill.

PROTECTION OF SEEDS FROM FOES

1. In cases where seeds pass through the bodies of animals, protection is afforded by a hard covering which resists the action of the digestive juices, e.g., berries, plum, cherry, clovers.

2. Spines, hairs, and prickles deter animals from consuming various seeds and fruits, e.g., awns in barley, spines in Bathurst burr.

3. Many seeds while immature are protected by sour or otherwise unpalatable substances, which often disappear when they have become ready for distribution.

Exercise 15.—Examine the fruits of common weeds, and try to discover how dispersal occurs in each case.

Exercise 16.—Make a list of fruits or seeds that you have observed clinging to sheep, horses, and cows.

Exercise 17.—Make a list of seeds or fruits which have been noticed moving on a windy day. Describe as far as possible any features which suit these for carriage by winds.

CONTROL OF FLOWERING

Several factors affect flowering chief of which are the genes or hereditary units, light, temperature, and hormones.

(a) *Genetic factors*:—The essential feature of flowering is the production of male cells in pollen grains and female cells in ovules. This is a device in nature which secures different combinations of material, the genes, inherited from the parents. It is called *genetical recombination,* and serves to produce at least some individuals capable of surviving under the conditions in which they may be placed, and capable, in farming, of satisfying the requirements of cropping, e.g., some varieties of fruit trees by flowering late in spring miss destruction of their flowers by frost. It is desirable that peas for canning be of a variety that, from the flowering point of view, produces its flowers almost simultaneously so that they are ready for harvest all together.

In plants, the most common sex-type is one in which both stamens with male gametes and carpels or pistils with female gametes are produced in the same flower. Such an individual is called *hermaphrodite* or bisexual, e.g., wheat, pea, dahlia. There are other kinds of plants, called *monoecious,* in which stamens and carpels are in separate male and female flowers on the same plant, e.g., maize, pumpkin, pine. The third sex-type of plant is *dioecious* with stamens and carpels on separate individuals, e.g., Chinese gooseberry, hop, N.Z. clematis. It is the genes in the individual plant which determine the sex-type of the plant. It is the genes too which determine to a large extent whether a plant will flower within one year from seed (annual habit) or within the second year (biennial habit) or over several years (perennial habit). The season of flowering is also largely determined by the genetical make-up of the plant.

(b) *Light* affects flowering. As we saw in Chapter 6, flowering with plants of a certain genetical make-up is accelerated by days of short illumination, called short-day plants; plants which form flowers only in long daylight days are called long-day plants. Short days, in certain plants like maize and squash, favour the production of female flowers over male flowers.

(c) *Temperature.* Before some annual plants will flower they must have been subjected to a period of either cold or heat during development. 'Winter' wheat and 'winter' ryecorn (higher yielding than spring types) will not usually flower in time to produce ripe grain if it is sown in the spring instead of the early winter.

These winter types can however be made to flower soon enough, when spring sown, if the seed before sowing is soaked to just start germination and is then given an artificial winter by chilling it to a temperature close to the freezing point of water for several weeks. This treatment is called *vernalisation.*

Other plants like cotton must go through a period of high temperature before they will flower. Most biennial plants like carrot, turnip, cabbage and beet must be vernalised either naturally or artificially before they are able to flower in their second year. If they are kept warm during the winter, they will not flower. Bulbs such as hyacinth can be vernalised so as to produce flowers out of season.

(d) *Hormones and the Control of Flowering.*—In Chapter 6 we saw how hormones have marked effect on growth, including flowering. Natural hormone within a plant determines whether or not a plant will flower. The application of artificial hormones of correct concentration to a plant promotes flowering. Pineapple plants can be made to flower when required by spraying hormone on to the growing tip. The first lot of flowers on tomato plants early in the season usually do not set fruit, but, if the flowers are sprayed with the appropriate hormone, the fruit becomes set without fertilisation and of course the fruit is seedless.

Hormones markedly affect the sex of flowers. With marrows, cucumbers and other cucurbits, which are monoecious, the first lot of flowers are all staminate or male so that no early setting of fruit is possible. By early application of hormone to a plant, the total amount of hormone in the plant is raised so that female flowers are produced early together with male flowers and so pollination and fertilisation can occur to produce fruit earlier than under natural conditions.

Ability to control flowering is very important, and some of the main benefits that may be derived from the application of such control are as follows:—

(1) By breeding crops that flower in a short growing season, cropping can be undertaken in places subject to very early and late frosts and in places of very low rainfall.

(2) By vernalisation of crops with long-life cycle it may be economic to grow such crops in places with short-growing seasons.

(3) Where fruit trees are likely to have their blossom killed by late frosts, hormone spraying of the blossom, by ensuring a fruit crop, may make fruit farming in such places less hazardous.

(4) Out-of-season flowers fetching high prices may be produced by vernalisation of bulbous and other plants.

(5) Plant breeding is also helped by controlling flowering for such purposes as crossing varieties that flower normally in different seasons.

IMPROVING PLANTS BY BREEDING

The yield and quality of plants can be improved temporarily by improving their environment or surroundings by proper cultivating, draining and manuring. They can also be improved permanently by breeding which includes selecting, testing and crossing.

VARIATION

If we examine a group of plants, especially those that are cross-pollinated, belonging to the same species, e.g. perennial ryegrass and turnips, we see that individuals are not all alike.* Some plants of ryegrass are more leafy than others, some have more flowers and seed than others. In seeking to improve a plant such as perennial ryegrass, plant breeders select those plants which have desirable features, e.g., leafiness, persistency, resistance to disease.

Selection of better individuals, namely those that have inherited superior genes from the parental material, is often very difficult. This is so on account of the difficulty in deciding whether the plant is superior because of superior genes or merely because it has had better growing conditions.

Breeders do their best to make sure, by painstaking *testing*, that an apparently improved plant is really improved. The plants to be tested are grown alongside others whose qualities are known, both under conditions as uniform as possible to overcome differences of soil fertility, and over several seasons to ensure that it is not only a certain type of season that suits the plant, and in several different soil types to find how widely it can successfully be grown.

---

* Cocksfoot, lucerne and white clover, grown as single plants all show a wide range of variation.

Selection

When a large number of plants of a certain species like perennial ryegrass are being observed with a view to raising an improved perennial ryegrass, the better plants are selected and used as the parents. All the inferior plants are rogued out before they flower and are destroyed, the mixed seed from the rest being saved. This is called *mass selection.* The more vigorous the rogueing the greater the improvement. Because the seed is obtained from many plants which cross pollinate, a proportion of the new generation is of inferior type, so that rogueing has to be continued over several generations to produce permanent improvement. However, there is a strict limit to the improvement effected by mass selection.

Hybridisation

For further improvements the breeder has usually to select two choice plants with different desirable features and cross them artificially to combine both features in one plant. Such was the position in producing the improved ryegrass called Short-Rotation ryegrass (H. 1). Italian ryegrass has superior palatability and superior winter growth while perennial ryegrass has superior persistency. By crossing a choice Italian ryegrass with a choice perennial ryegrass and selecting from the progeny, Dr. Corkill and his assistants at the Grasslands Research Station were able to produce Short Rotation ryegrass which possesses to a large extent the superior qualities of both parents. The large amount of work involved in hybridising is also glimpsed by referring to wheat. When Dr. Hilgendorf and his assistants at the Wheat Research Institute were hybridising wheat, about 80,000 different individuals were obtained from crossing the varieties White Fyfe and Tuscan. Out of all these hybrids, one, called Cross Seven, proved very successful in the main wheat-growing areas of New Zealand.

Mendelism

The first indication of the mechanism by which hybridisation proceeds was published by an Austrian monk and schoolteacher, Gregor Mendel, in the year 1866. Not until 1900, however, was the importance of his discovery realised by other scientists. His principles of breeding, still true in essentials, have been extended to make up the science of *Genetics* and modern Mendelism. A brief indication of a few of the simpler features of modern Mendelism is as follows:

If a plant is self-pollinated (*selfed*) and it gives seedlings which grow into plants just like itself, and, if these plants in their turn are selfed and give the same kind of plants, then such a plant is said to breed true. If its male and female gametes, in pollen grains and ovules respectively, are all alike in the characters observed, it is said to be *homozygous* in respect to those characters. If a plant, e.g., sweet pea, breeds true for red flower colour, it means that every one of its pollen grains carries in its male gamete (male sex cell or sperm) a tiny piece of hereditary material, a *gene,* which controls the colour of the flower making it red. (Thousands of genes all situated in the nuclei of the cells control the development and the inheritance of flowering plants.) This gene for red flower colour can be represented by the letter R. Similarly every one of its ovules carries, in its female gamete (female sex cell or egg), the same kind of gene, R. On fertilisation the combination of the R gene of the sperm with the R gene of the egg gives the zygote (the first cell of the new generation) a double lot of the red flower gene, RR. This zygote is therefore, as regards flower colour, homozygous for red.

When the zygote develops by cell division into a mature plant all the nuclei of the cells of the plant receive the same number and kinds of genes as the original zygote cell. Hence this plant will breed true for red flower colour because it can pass on only the gene R for flower colour.

If a self-pollinating plant produces offspring which do not breed true, say some of the offspring of a red-flowered sweet pea produce white flowers while other offspring of the same plant produce red flowers, then the gametes of that plant must differ in their genes for flower colour. Such a sweet pea is said to be *heterozygous* for flower colour.

Now the inheritance of every individual plant is a double inheritance, half from the male parent by way of the male gamete and half from the female parent by way of the female gamete. Therefore the genes in a plant must exist in pairs, the one from the male and the other from the female. These gene pairs may be of the same kind, as we saw above with red flower colour represented by RR, or they may be of different kind, e.g., one member of the gene pair may cause the absence of flower colour, that is white, and this may be represented by the letter r. This gene pair would be represented by the letter combination Rr and the zygote containing it would be called a *heterozygote*. Mendel discovered several contrasting kinds of gene pairs in the edible pea, e.g., tall/dwarf, yellow cotyledons/green cotyledons. Examples of other gene pairs are:—early maturing/late maturing (plants), brown eyes/blue eyes (human beings), hornless/horned (cattle).

INHERITANCE OF ONE PAIR OF RELATED GENES

If we take a true-breeding red-flowered snapdragon and a true-breeding white-flowered snapdragon, we know all the gametes of the red snapdragon carry the gene R and all the gametes of the white snapdragon carry the gene r. When cross-pollinating the red with the white, we would remove the anthers from the red parent before they are ripe, protect the emasculated plant from other pollen, and then transfer with a fine brush or other means the pollen from white-flowered snapdragon to the protected stigmas in the flowers of the red-flowered plant. Following this cross-pollination fertilisation should occur followed by zygote and seed formation. Plants from this seed are called *hybrids* and they will all produce pink flowers, i.e., flowers of colour intermediate with the flower colours of their parents.

Thus:—RR × rr = Rr.

As these hybrids with genes Rr all produce the intermediate flower colour, pink, the genes R and r must have about equal effect on flower colour. If the hybrid pink-flowered snapdragons are now selfed, and we have a large number of their progeny to observe, we shall see that the progeny are of three kinds as regards flower colour and the three kinds are produced in numbers bearing a definite proportion to one another. About half of them will be pink like their parents and a quarter red and a quarter white like their grandparents.

i.e., 1 red (RR) : 2 pink (Rr) : 1 white (rr).

This is explained by two principles:—

(1) A gamete can carry only one of the members of a gene pair at a time, i.e., either R or r, not both.

(2) Gametes with the R gene and gametes with the r gene occur in equal numbers.

As we have seen in connection with zygote formation, it is a matter of chance which pollen grain (bearing the male gamete) reaches a particular ovule (bearing the female gamete) to fertilise it. So it is a matter of chance whether an R ovule is fertilised by an R pollen grain or by an r pollen grain, and an r ovule fertilised by an R pollen grain or an r pollen grain. As the different kinds of pollen grains and the different kinds of ovules are produced in equal numbers in each case, then the chances are equal that the two kinds of fertilisation will occur in both cases.

i.e., there are the following four possibilities:—

R ovule fertilised by R pollen grain produces RR offspring
R ovule fertilised by r pollen grain produces Rr offspring
r ovule fertilised by R pollen grain produces Rr offspring
r ovule fertilised by r pollen grain produces rr offspring

Or the selfed hybrids produce:—

1 RR : 2 Rr : 1 rr.

Exercise 18.—Take 400 small pieces of cardboard and label 200 of them with the letter R to represent ovules containing female gametes with gene R in hybrid snapdragons produced as above. Similarly label the other 200 cards with the letter r to represent pollen grains containing male gametes with gene r. Place 100 cards of each kind in each of two boxes and shake up each box well to mix the cards. Label one box, 'pollen parent', and the other box, 'ovule parent'. Every pupil in the class then takes one card from each box and places them as a pair on a table to represent fertilisations. These 'fertilisations' are repeated until all the cards are used up. Then the numbers of each kind of pair RR, Rr, and rr are noted on the blackboard. See if the ratio is approximately 1 : 2 : 1. (Modified from '*Notes on Mendel's Experiments in Heredity*' by E. J. Godley in '*N.Z. School Science*', No. 11, July 1957.)

A similar situation occurs when Shorthorn cattle are crossed, pure-breeding red-coat coloured × pure-breeding white-coat coloured.

DOMINANCE

Inheritance is not often as easy to trace as that discussed with snapdragons. One of the complicating factors in inheritance is dominance. In snapdragons the action of the genes in Rr hybrids was about equal. It is more common, however, for one member of the pair of related genes to have a stronger effect than the other member. The stronger one is said to be *dominant,* the other *recessive*. This is clearly shown with red coloured and white coloured sweet peas. If true breeding red flowered sweet pea plants, RR, are crossed with true breeding white flowered sweet pea plants, rr, the hybrids are not all pink flowered but are all red flowered. The gene for red (R) masks or dominates the gene for white (r). When the hybrids are selfed, instead of the offspring being of three kinds, as regards flower colour, they are of only two kinds, those producing red flowers and those producing white and the ratio, instead of being 1 : 2 : 1, is 3 of red to every 1 of white.

A situation similar to this occurs with cattle when bulls of a hornless breed (e.g., Aberdeen-Angus) are mated with cows of a horned breed (e.g., Hereford), the gene for hornless being dominant to the gene for horned.

HYBRID VIGOUR

When two dissimilar varieties of plants (or animals) are crossed, the offspring are usually intermediate in the size and vigour of the parents. Some pairs of plants (or animals), however, when crossed, produce offspring markedly bigger and more vigorous and productive than either parent. This latter situation is called hybrid vigour. In maize breeding hybrid vigour has been found to be specially valuable. Maize is a plant which, if left to itself, will usually cross-pollinate. By selfing certain varieties over several generations, i.e., by *in-breeding* the varieties, plant breeders produce *pure lines* of maize, i.e., maize that breeds true. Even the best of the pure lines of maize are much smaller and weaker than the original parents but, by crossing two of the pure lines, say A and B, a hybrid set of plants, say E, are produced having greater vigour than either A or B. Similarly, two other pure lines, C and D, are crossed to produce another set of hybrids, say F. By crossing hybrid E with hybrid F, a very vigorous and high-yielding *double hybrid,* G is produced.

Thus:—A × B = E (hybrid)
C × D = F (hybrid)
E × F = G (double hybrid)

More than 90 per cent of the maize grown in U.S.A., and much of that grown in New Zealand is planted with hybrid seed.

TO DEMONSTRATE HYBRIDISATION

Exercise 19.—In one area about the middle of November sow several rows of pop corn about 5 feet apart. Then at intervals of one, two, and three weeks later sow rows of sweet corn between the rows of pop corn, one between every two. In another area several hundred yards away from the first area sow a few rows of sweet corn only. In the first area probably early in February remove the tassels (staminate flowers) from the middle rows of sweet corn as they appear. Leave the two types to cross-pollinate by wind-blown pollen from the tassels of the pop corn falling on the silks of the sweet corn. When the cobs are harvested, compare the cob size and the grain from the pop corn × sweet corn with the corresponding features in the isolated sweet corn. Next year sow the hybrid corn and compare the resulting cobs with those of the original parents.

TO DEMONSTRATE VARIATION

Exercise 20.—Collect seed of cocksfoot from several different kinds of places, e.g., road sides, waste places, orchards, and pastures. Also get samples of commercial seed, e.g., Grasslands certified, and uncertified. Sow each lot of seed in a seed box and later transplant as individual plants one foot apart each way. As the plants develop note variations in such features as speed of establishment, leafiness, height, time of flowering, amount of seed, and persistency.

TO DEMONSTRATE CROSS-BREEDING

Exercise 21.—(a) With peas. In sweet peas and garden peas self-pollination takes place within the keel at an early stage of development. Examine flowers to ascertain at what stage the pollen is shed. To effect cross-pollination bend back the wing petals and slit up the keel to expose the stamens. Remove the stamens individually taking great care that no pollen is shed and no damage done to the style and stigma. The flower is now emasculated ready to serve as the female parent. From the male parent select a flower in which the pollen has just been, or is about to be, shed. Using a camel's hair brush or other means transfer the pollen to cover the stigmatic surface of the emasculated flower. Readjust the keel and other petals and tie on a small label indicating the parental varieties. There is no need to cover the flower. Practise this operation at a desk before attempting it on the plant in the field. Suitable varieties which have contrasting characteristics are:—

Greenfeast:—Seed coat green, seeds wrinkled, cotyledons yellow, maturity medium to early, height medium to dwarf, white flowers.

Blue Prussian:—Seed coat bluish green, seeds round and smooth, cotyledons green, maturity medium to late, height medium, flowers white.

Partridge:—Seed coat coloured, seeds dimpled, cotyledons yellow, maturity very late, height very tall, flowers purple.

NOTE:— To ensure that the three varieties have flowers available at the same time, Partridge should be sown early followed by Blue Prussian and Greenfeast at two week intervals.

The seed arising from the cross should be examined and in due course resown to produce second generation seed and this again sown to produce third generation seed. Observe the segregation of characters that takes place in seed and plant characters.

(b) Maize:—This is a convenient plant in which to demonstrate the result of cross-breeding. If a yellow-grained variety and a white-grained variety are grown side by side, some cross-pollination is likely to occur and the cobs harvested on the white-grained plants will show some yellow grains. If the tassels on the white-grained plants are removed as they appear *all* the grain produced on these plants will be yellow. See Exercise 19 (To Demonstrate Hybridisation).

MUTATIONS OR SPORTS

Entirely new characters that appear suddenly and occasionally in plants, if they are heritable, are called mutations or sports. They may involve whole plants or only branches, but whichever it is, changes in the genes have occurred. Most of our horticultural plants arose as mutations, e.g., nectarine, navel orange, Spencer sweet pea. When they first appear, they are often regarded as freaks. Mutations provide an important means of improving plants by breeding, for those that are better than the original plants are selected, and either isolated for getting seed by selfing, or propagated by vegetative means such as by cuttings, budding and grafting.

In this brief discussion of plant improvement by breeding, we have had glimpses of that branch of science which has very important relations with Agriculture, the science called Genetics. By careful selection, breeding and testing, it has been possible to make outstanding improvements in crops, or, as an old saying has it, 'Two blades of grass are made to grow where one grew before.' Plant breeding will certainly play a prominent part in the future in the providing of sufficient food for the expanding population of the world.

READING

Agricultural Botany,
Yeates and Campbell
Practical Plant Breeding,
Lawrence
**Rural Education Bulletins,*
July, Aug., Sept. 1956
**New Biology,*
23 May 1957
**Science News,*
18 Nov. 1950
* Mainly for the teacher

FILMS

(The National Film Library)
'Pollination'
'Life Cycle of Maize'
'Seed Dispersal, Parts 1 and 2'
'How Plant Breeding helps the Farmer'

8

The Formation of Soil

JUST as plants and animals *inherit* their characters from their parents and *develop* those characters in an environment, so do soils inherit characters from parent rock, and develop, along with plants and animals, under conditions of climate and topography and over a period of time. The longer the time, which usually means thousands of years, the greater the development of the soil. So a soil, like a plant or an animal, may be considered to have a *life cycle* beginning with the breaking up of the parent rock, continuing with the transport of the rock fragments, the passage of substances in solution or in a fine state of division from one part of the soil to another, relations with plants and animals, and ending only when the soil is removed by erosion.

Viewed broadly the climate, especially rainfall and temperature, determines the vegetation, and both the climate and the vegetation determine the kind of soil, and all of these determine the kind of agriculture in that place. If a soil map of the world is compared with world maps of climate, of natural vegetation and of major crops, it is clearly evident that this relationship does exist. The soil, the climate, the vegetation and the crops all follow the same general pattern of situation. Take for example, the soils of Russia, the first country to understand that over a long period climate exerts a far greater effect on soil formation than any other factor. The following main soil groups are recognised:—In the Arctic Circle where only lowly plants like mosses, lichens and small shrubs will grow, there are boggy soils called *tundra soils;* in the cold temperature, high-rainfall zone where pine forests grow are the ashy-grey soils called *podzols;* further south in the cool temperate, low-rainfall zone where tussock grasses grow are the black soils, the *chernozems;* and right in the south in the warm temperate, arid zone with sparse scrub are the dark brown *chestnut soils* (brown steppe soils). All of these soils occupy vast areas, and are, in every case, remarkably uniform in spite of the underlying rocks not being uniform.

Some people regard soil as just dirt. Farmers and gardeners, being closer to nature, know it as the material in which plants will grow, and this is a good definition of soil. Of course farmers and gardeners want a fertile soil, one in which good plants will respond to the best possible degree, such response being limited only by their inheritance. Not all soils are equally fertile; some need special treatment like draining and liming to become fertile; some are specially suited to certain crops; others need much water, many need the addition of minerals such as phosphate. However, whatever the soil, it contains the following five essential components:—

1. *Inorganic matter,* i.e., material which has never been alive—the inorganic constituents are known as sand, silt, and clay, i.e., the mineral part of the soil derived from the rocks of the earth's crust.

2. *Organic matter*—material derived from plants and animals.

3. *Micro-organisms,* especially bacteria and fungi, which live in the organic matter helping to decompose it. (See Chapter 12.)

4. *Water* which forms films around the soil particles. (See Chapter 10.)

5. *Air* which fills the spaces between the soil particles. (See Chapter 10.)

The relative proportions of these components depend upon the extent and kind of soil development which will be discussed in this chapter. The last three of these constituents will be considered in subsequent chapters, while the first two being more directly concerned in soil formation will be dealt with in this chapter and the next. Calcium carbonate is present in some soils of good quality, but it is not absolutely necessary for the healthy growth of all plants—indeed it is harmful to some, e.g., heaths. Hence it has not been included among the essential components of a soil.

General acceptance is now accorded the statements of geologists that everything of which the earth is composed was once in a state of vapour, because of the great heat which prevailed. As cooling took place many of the substances of which the earth is made became liquid and finally solid. The masses of rock which resulted from this cooling make up the inorganic portion of soil. Those rocks such as basalt, andesite, rhyolite and granite derived directly from the cooling are called *igneous rocks;* those such as sandstone, greywacke, and argillite formed by the weathering of older rocks and deposition of the fragments are called *sedimentary rocks;* and those such as schist and marble formed from older rocks by great pressure and heat are called *metamorphic rocks.*

THE CHANGE FROM ROCK TO SOIL

The intermediate stages between solid rock and cultivated soil can often be observed in exposed sections—road and railway cuttings, quarries and cliffs.

While broken fragments of rock make up the inorganic part of a soil, it is not until the inorganic matter is mixed with organic matter, microbes, air and water that a soil is formed. Soils as we know them today inherited their inorganic particles from rocks, accumulated their other constituents and developed their characters under the influence of soil forming factors. Some soils, such as those formed from recent fixed sand dunes, have much inorganic matter and little organic matter. At the other extreme there are peat soils with little inorganic matter and much organic matter.

WEATHERING AGENTS

The gradual conversion of solid rock into the inorganic part of soil is known as *weathering,* and is due to a number of simple natural forces called *weathering agents.* These are:

1. *Changes in Temperature,* such as are involved in passing from day to night, or from season to season, play an important part in the breaking up of rocks. This result is mainly due to the fact that most rocks are not uniform throughout, but are made up of myriads of tiny crystals of several substances distinct from one another in composition and properties. For instance, the widely occurring rock *basalt* contains minerals known as *felspar, augite,* and *magnetite.* The general rule is that a rise in temperature causes a substance to increase in size, while a fall in temperature causes it to decrease. Were rocks made of one substance the continual changes in temperature would result in but little except changes in size such as repeatedly occur in the case of masses of iron and other metals, but the crystals of the different substances in a rock expand and contract different

amounts under the same change in temperature. The effect of this becomes clear if we imagine a crystal of large expansion to be surrounded by a number of comparatively small expansion when subjected to the same change in temperature. Strains would occur so that the rock constituents would have a tendency to work apart, thereby forming fine cracks or fissures. As soon as a rock is traversed more or less by a network of fissures the operations of the other weathering agents become possible, but in general the initial and probably the chief agent causing the breaking down of solid rock is the ever-occurring change in temperature, working slowly, silently, and inconspicuously, and the freezing of water in the cracks produced by the stresses following changes of temperature.

Exercise 1.—Heat a piece of glass tubing and plunge it into cold water. If the temperature is suitable the glass will remain intact, but is cracked into thousands of divisions. This illustrates in an exaggerated manner the effect of sudden changes in temperature upon rocks.

Exercise 2.—Obtain a piece of rock such as granite or road metal and wash it very thoroughly in water. Heat the rock in a flame, and plunge it into a beaker of cold water. When cold remove the rock, and after allowing the beaker to stand for a minute pour off the clear water. Some fragments of rock should be discovered at the bottom of the beaker.

2. *Water,* to the extent of about three-quarters of the total rainfall, sinks into the ground, carrying with it *oxygen* and *carbon dioxide,* which greatly increase the extent of its action. Water is an almost universal solvent; it attacks and dissolves practically all substances found in rocks. If some substance easily dissolved is removed from a rock, the rock is honeycombed, and its resistance to other forces lessened. Water also combines chemically with substances present in rocks, e.g., with substances such as silicates producing hydrated aluminium silicate, e.g., Kaolin clay. Silica (Silicon oxide) in rocks is not easily decomposed so that it tends to form the sandy part of a well developed soil. However, if decomposition is incomplete, the particles of rock which are unaffected act as sand.

3. *Freezing.*—This is really a special case of the first agent, changes of temperature. Water acts powerfully as a disrupting agent when freezing occurs. Through the expansion that takes place when water is changed to ice a very powerful pressure is set up. So long as water, occurring in the crevices in a rock, remains in a liquid form, its effect as a weathering agent is

comparatively slow, but when it is converted to ice it pushes the parts of a stone asunder. The effect of frost becomes evident after a thaw, when the hardest stone may crumble into a shapeless mass. Undoubtedly this action of water is one of the most powerful agencies in the formation of soil in temperature regions. For this reason it has been found necessary in very cold climates to paint statuary with a waterproof material to enable the stone to retain its original smooth surface. Cleopatra's Needle, which had retained its smooth surface for centuries in Egypt, soon became affected after its removal to London.

4. *Running Water.*—Moving water acts as a powerful weathering agent. So long as water is free from gritty matter, its power of wearing away rocks is but limited, but as soon as it carries solid matter in suspension, its power is greatly increased. The particles carried along by the water have, on the material forming the bed or sides of the water course, an effect similar to that of filing or rubbing with sand-paper. Further, as the particles are being borne along they come into collision with one another, and thereby become more and more pulverised, thus giving rise to fine sand and silt.

5. *Oxygen.*—This gas is an important weathering agent. Many substances in rocks combine with oxygen to form new compounds which in most cases are easily disintegrated in comparison with the original material. The mineral *augite* may be taken as a typical case. It contains iron compounds which by combining with oxygen form *iron oxide* or rust. To the presence of this iron oxide, derived from the weathering of minerals containing iron compounds, is due in most cases the reddish colour of certain soils. Similarly the yellow colour in soil is commonly due to hydration of iron oxide. We can observe the effects of oxygen and water on rocks by examining surface stones. They will be found to be more or less yellow or red on the outside, and when they are freshly broken it is possible to trace a transition from a friable reddish surface to a comparatively dark hard crystalline centre. The difference is due to the fact that the surface has been *oxidised,* and *hydrated,* i.e., acted on by the oxygen and by water while the centre is unoxidised and unhydrated.

6. *Carbon dioxide.*—This gas is an important weathering agent, chiefly because of the increased dissolving power that it bestows on water in which it is moderately soluble. Soil water

practically always contains carbon dioxide gas in solution. Rain water absorbs some in falling through the air, but the major part of it comes from the soil itself where carbon dioxide gas is liberated by plant roots, and by organisms during the decomposition of organic matter. This further charges the rain water, and forms an acid capable of dissolving many substances in the soil not soluble in pure water. Thus limestone and other substances insoluble in pure water, are acted upon by the carbonic acid forming *bicarbonates*. It may happen that the carbonic acid dissolves the cement which is binding particles of rock together, in which case rapid disintegration follows. On the other hand it may attack the purer limestone rock carrying away the limestone in solution, and leaving behind the residue which in time forms the soil. In many instances of this kind the leaching by means of carbonic acid has been so thorough that the resulting soil is decidedly deficient in lime. The lime remains in solution only while the solvent is charged with carbon dioxide. On evaporation or exposure to the air the soil water will gradually lose the carbon dioxide, and the limestone is in consequence thrown out of solution and re-deposited elsewhere. Such has been the mode of formation of stalactites and stalagmites, while the solvent action of carbonic acid accounts very largely for the caves so common in limestone country.

7. *Living Agents.*—Animals and plants in a soil, by disturbing the soil and helping air and water to pass through, enable other weathering agents to work more effectively. *Burrowing animals,* especially earthworms and insects, in turning over the earth expose fresh material to weathering and help in the breaking down of rock. *Plant roots* play a part in the breaking down of rocks. They advance into cracks, even those of very small size, and as they grow in thickness they exert a considerable force which tends to increase the size of the fissures. They also attack rocks by excreting at their growing regions an acid—largely carbonic acid—which facilitates the solution of many mineral substances.

When parts of plants or whole plants die, the products of decomposition of the debris include also carbon dioxide and this carbon dioxide takes part in weathering. Thus, alive or dead, plants, animals and microbes continuously help in the breakdown of rock into soil.

SOIL DEVELOPMENT

Soil scientists know that soil is a natural object, continually changing and full of living things. The processes of development in a soil are going on all the time. The soil water is carrying substances in solution or in suspension from one part of the soil to another, chiefly downwards; the temperature of the soil varies daily and seasonally; its plants are taking up minerals from the soil solution and returning them to the surface in their litter; its microbes change in numbers and in activity from time to time; and its earthworms mix the organic matter with the mineral matter and aerate the soil.

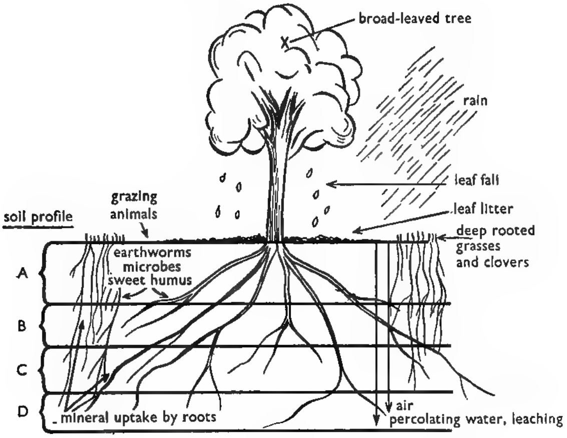


FIG. 44. The soil organic cycle

The kind of soil formed as a result of the processes of development depends upon the climate, the vegetation, the kind of rock upon which weathering agents have worked, the slope of the land, and the time involved. Let us consider further these *soil forming factors*:—

(a) *Climate.* Rainfall and temperature are the chief factors of climate concerned in soil formation. As rainwater moves down through the soil, the surface humus charges it with carbon dioxide and humic acid turning it into an acid solution. Minerals are dissolved by this percolating acid solution and are removed, a process called *leaching,* being either deposited in the lower layers or carried away in the drainage. So soils, developed under high rainfall, tend to be less fertile than those under low rainfall. The climate also determines the vegetation which in turn determines soil.

(b) *Vegetation.* Plants, by taking up minerals from a soil and building them into their bodies, are carrying out a process the reverse of leaching. As the plants drop their leaves and twigs and the organic matter turns into humus in the soil, the minerals again become available to the plants and the fertility of the soil tends to build up. Some plants are better than others in this respect. Under some kinds of trees the soil is sweet and fertile, while under other kinds it is sour and impoverished. Broad-leaved, evergreen trees like puriri and tawa, and deciduous trees like oak, take a great deal of minerals from the soil and return much of them to the soil thus building up its fertility. On the other hand trees such as rimu, totara, beech and kauri, draw so little mineral from the soil that they return little, and the leaching process in time impoverishes the soil. (See Fig. 44.)

(c) *The Parent Rock.* If a soil is not old or if it has developed under a low rainfall, then its content of minerals suitable for plant growth is largely determined by the mineral content of the parent rock and by the ease with which the rock will break down, or weather, to release those minerals. The more leached a soil is the lower is its content of minerals in reach of most plant roots. Of course, no matter how young a soil is and how little leached it is, if the parent rocks were low in the minerals required by plants, then the resulting soil must also be low in those minerals. A soil inherits its minerals. Thus recent volcanic soils on the Auckland isthmus are fertile because they weather easily and are rich in essential minerals derived from the basalt rock. Older volcanic soils in North Taranaki, on the other hand, are not fertile until potash fertiliser is added to them and many pumice soils of the Central Plateau of the North Island must have cobalt to be fertile and to grow healthy grass. The parent rocks of nearly all the soils in New Zealand are deficient in the element phosphorus so that phosphate fertilisers are in great demand.

(d) *The Slope of the Land* (Topography). Where the land is steep the soil tends to move down the slopes as it is formed and is replaced by new soil with fresh supplies of minerals. These soils of steep slopes are called *skeletal soils.* They comprise over 50 per cent of the soils in the occupied land of New Zealand.

Though these soils are shallow and low in organic matter, they can be fertile provided the parent rock underlying them contains all the essential minerals and there is a good rainfall. For example, in the steep papa country of the East Coast of the North Island the parent rock is rich in lime and other minerals and slips soon heal over with vegetation.

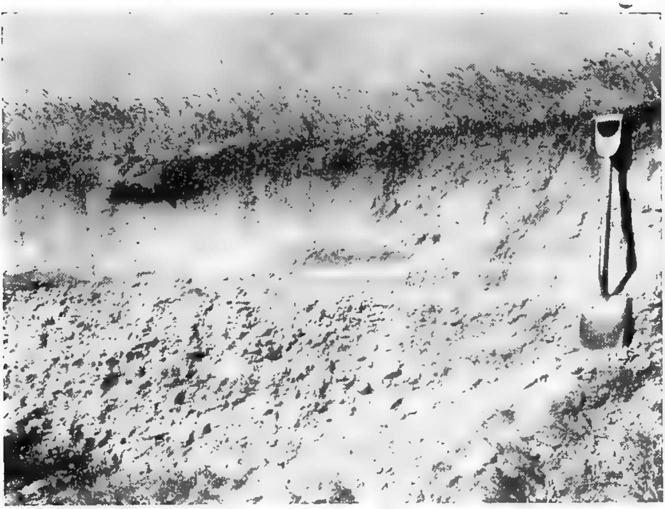


FIG. 45. Profile of a soil of Recent origin, Canterbury Plains (*Soil Bureau*)

(e) *Time Involved.* The life of a soil is usually measured in many thousands of years. In a wet, humid, mild climate, such [illegible]n the North Island of New Zealand, the older the [illegible]ertile it tends to become. As already mentioned, a soil has a life cycle starting with the weathering of the parent rock and ending with its removal by erosion. Soils may be young, and little developed, or old and well developed. A young soil, called a *recent soil,* may be a few hundred years old, as for example, most of the alluvial plains of Canterbury and the terraces of the Wairarapa, or less than one hundred years old as in the case of some of the alluvial plains of Canterbury, e.g., those near Christchurch and the soil formed from the mud and ash erupted from Lake Rotomahana and Mt. Tarawera in the year 1886. Being the least leached, recent soils are usually the richest soils, provided they are fine in texture.

Older soils are more leached and are classified into groups determined primarily by climate and by parent material. (See section on 'The Main Soil Groups in New Zealand'.)

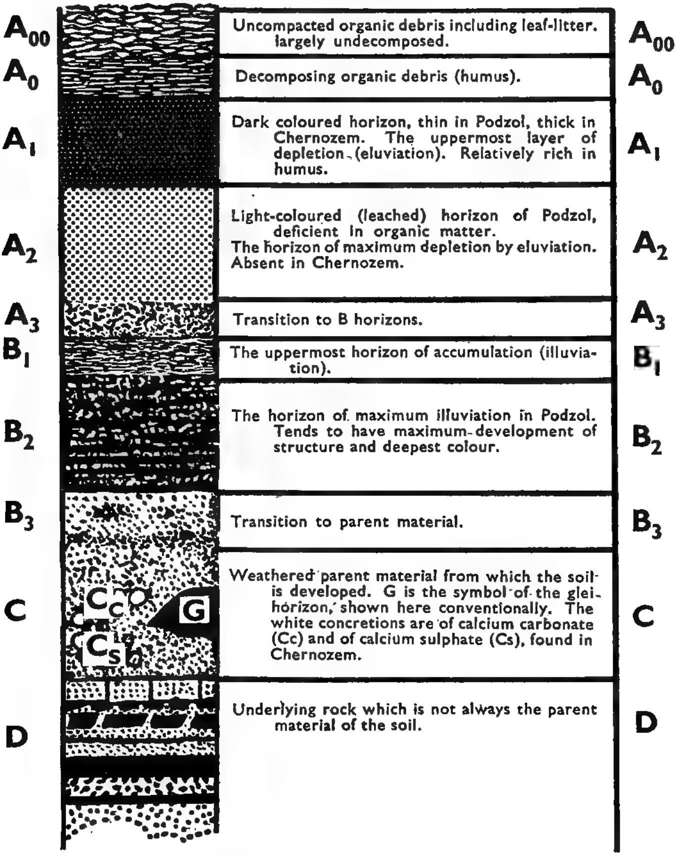
SOIL SURVEYS

LOOKING AT VERTICAL SECTIONS OF SOILS

As a farmer's income comes from livestock products and crops, all dependent on soil, it is essential that he knows his soils very well. While a farmer can reach some understanding of the capabilities of the soils on his farm, with the aid of soil scientists he can gain knowledge of his soils much more quickly and more thoroughly. A soil scientist, a *pedologist,* as he is called, not only goes deeper into thinking about soil than a farmer does but he also actually studies the soil to a greater physical depth than does a farmer who, except when he digs a post hole or a drain, goes little deeper than about 9 inches. Pedologists find that, by digging down into the subsoil to a depth of 3 feet or so and then studying the layers or *horizons* of the soil, they can arrive at a very good understanding of the soil. They study the *soil profile* which is a vertical section of the soil showing the horizons from the surface down to the underlying rock. The depth of the profile, however, is really determined by the depth to which the forces of climate and living things are effective in soil formation. It is usually about 3 feet. Soil profiles can be seen in such places as road cuttings, slips, quarries, and post holes, and they can be observed more intensively by boring down into the soil in many places on a given area with an auger. A skilled pedologist, by observing the profile of a soil, can tell not only the changes taking place in the soil at present but also the changes that have taken place in the past, i.e., he can tell the history of the soil.

SOIL PROFILES

Except in the case of recent soils, the importance of studying soil profiles to understand the properties of soils can hardly be over-emphasised. In a temperate climate where the rainfall exceeds 20 inches, such as holds over most of New Zealand, water percolates through the soil. Acidified by carbon dioxide and humic acids, from the decomposition of organic matter, this percolating water takes with it mineral elements essential for plant growth, such as calcium, potassium and magnesium, as soluble carbonates and bicarbonates. At the same time hydrogen displaced from the acid solution enters the clay and the humus making them acid. This leaching process is accompanied by the downward movement also of the fine clay particles and iron and aluminium oxides. So the upper part of the soil, often called topsoil, tends to become acid, and the lower part, the subsoil, tends to become sticky and compact, and, if much iron



A_{00}	Uncompacted organic debris including leaf-litter, largely undecomposed.	A_{00}
A_0	Decomposing organic debris (humus).	A_0
A_1	Dark coloured horizon, thin in Podzol, thick in Chernozem. The uppermost layer of depletion (eluviation). Relatively rich in humus.	A_1
A_2	Light-coloured (leached) horizon of Podzol, deficient in organic matter. The horizon of maximum depletion by eluviation. Absent in Chernozem.	A_2
A_3	Transition to B horizons.	A_3
B_1	The uppermost horizon of accumulation (illuviation).	B_1
B_2	The horizon of maximum illuviation in Podzol. Tends to have maximum development of structure and deepest colour.	B_2
B_3	Transition to parent material.	B_3
C	Weathered parent material from which the soil is developed. G is the symbol of the glei-horizon, shown here conventionally. The white concretions are of calcium carbonate (Cc) and of calcium sulphate (Cs), found in Chernozem.	C
D	Underlying rock which is not always the parent material of the soil.	D

FIG. 46. The soil profile. A diagram to explain symbols used in descriptions and the sequence of horizons

(From S. G. Brade-Birks: *Good Soil*, p. 121) is deposited at a constant level, to form an impervious, hard iron pan. Under such conditions there is the development in the soil of layers or horizons. (See Fig. 46.)

The horizons from which substances have been removed are called the A. or eluviated horizons, and the horizons in which substances are deposited or precipitated are called the B. or illuviated horizons. Further down is the C. horizon which represents rock in the early stages of weathering. Sometimes completely unweathered rock, not necessarily the parent rock, underneath the profile is labelled D.

FIG. 47. Describing a soil profile

Where the rainfall is highest and the plants, such as conifers and small-leaved trees, growing on the soil take little from the soil, the loss by leaching is the greatest. A high degree of acidity develops and this leads first to slow decomposition of the organic matter and to accumulation of raw organic debris as a surface horizon, the Aoo horizon, and second to the loss of iron and aluminium oxides from the upper regions producing a bleached horizon, the A2, horizon. Some of the humus, dissolved from the surface, drains down to the iron pan where it becomes deposited as a humus pan in the B2 horizon. A soil with this sort of profile is called a *podzol* (from Russian words, 'pod' = under, and 'zola' = ash). If the leaching and depositing have been going on for a very long time producing great development of the profile, then very poor soils are formed called *strongly leached podzols,* such as are present in the gumland soils of Northland and in the pakihi soils of Westland.

Where the natural plant cover consists of broad-leaved evergreen trees, deciduous trees and grasses and where the rainfall is not so high as with podzols, there is less development of acidity and less loss by leaching. Fewer and less marked horizons develop and the soil generally has a brownish colour and

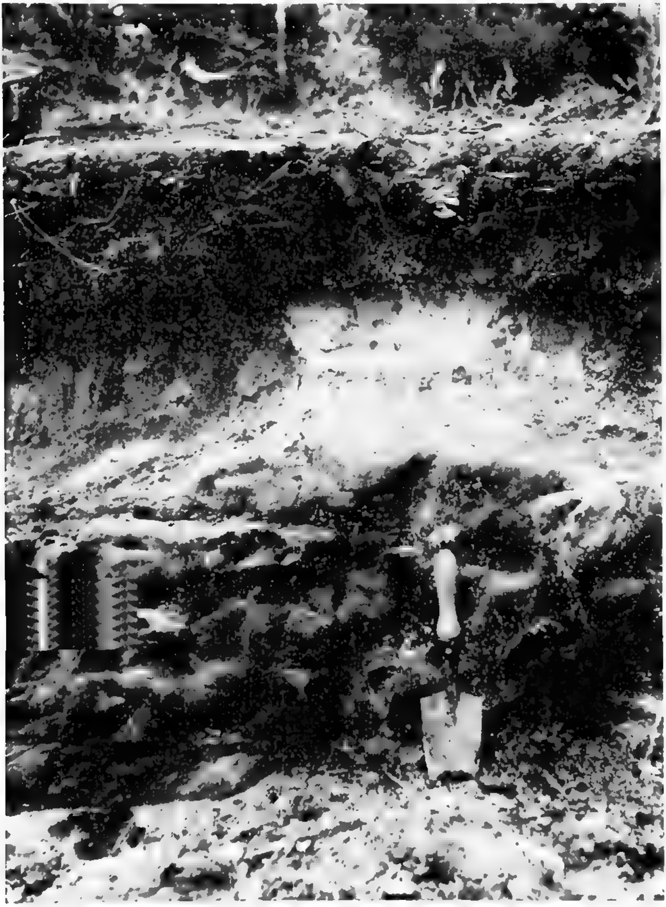


FIG. 48. Profile of a podzol soil, Awanui, North Auckland (*Soil Bureau*)

a crumbly structure. The organic matter, being less acid, decomposes more readily and is usually well distributed by earthworms. These soils are called *yellow-brown earths*. They are common throughout the wetter parts of Gisborne, Hawkes Bay, Wairarapa, Wellington, Nelson and Southland. Similar soils formed on fine volcanic ash are common in the Waikato and Taranaki districts and are called *yellow-brown loams*.

Exercise 3.—To examine soil profiles. In an area containing different kinds of soils, dig holes about 3 feet deep to expose the profile in each case. Observe and measure the thickness of each horizon. Make a large sketch of the profile. Note on the sketch for each horizon its thickness, colour, the presence of roots, earthworms and other forms of life; the presence of concretions of ironstone or other substances; whether it has a granular or a compact structure. Handle a sample of the soil from each horizon and note its texture, whether gritty, silky or sticky. Try to account for any differences you see in the various profiles.

THE MAIN SOIL GROUPS IN NEW ZEALAND

Being very hilly, having a varied climate with a variety of original vegetation, and having also parent rocks of great variety, New Zealand has soils of wide diversity making a pattern of great complexity. This can be readily appreciated by studying the soil maps of New Zealand. (See Fig. 56.)

The soil types and soil suites are classified in one of the following main soil groups, the chief regions of their occurrence being given in each case.

A. ZONAL: Those developed mainly by climate and vegetation.

(1) *Podzols*. The most highly-developed podzols occur in Northland on the gumlands originally under kauri forest, and in the Catlins district of Southland where the rainfall is about 50 inches per annum; also in Westland, the pakihi soils, under about 100 inches of rainfall per annum, are both strongly podzolised and gleyed. Lesser degrees of podzolisation have been developed under beech forest in the wetter parts of the North Island.

(2) *Yellow-brown earths*. These occur where the annual rainfall is between 40 inches and 70 inches, in mid-Auckland, W. Taranaki, S.W. Hawkes Bay, and W. Wairarapa, Nelson, Otago and Southland. The top soils are silt-loams, grey to greyish-brown

in colour and the subsoils are slightly heavier, yellow-brown in colour and of nutty structure. They generally make excellent pasture lands.

(3) *Yellow-grey earths.* In regions with 20 inches to 40 inches of rainfall a year, and chiefly occurring in Hawkes Bay, Wairarapa, Manawatu, and Canterbury downlands. The surface soil is generally a grey silt-loam of weak structure and the subsoil is yellow flecked with brown or grey and has a nutty structure. At about 18 inches below the surface there is commonly a thick, hard compact layer. These soils are suited either to cropping or to pasture.

(4) *Brown-grey earths.* These occur where the rainfall is less than 20 inches per annum, chiefly in Central Otago and Mackenzie Plains. Usually these soils are made up of sandy loams, brown-grey in colour with friable, stony subsoil. They require irrigation to be highly productive.

B. INTRAZONAL: These are soils the development of which is affected mainly by the parent rock or by the closeness of the water-table to the surface.

(1) *Rendzina soils* derived from limestone or shelly parent rock in Northland, S. Hawkes Bay, and in the limestone belt of Canterbury and N. Otago.

(2) *Pumice soils* of the central North Island (primary podzolic soils). Usually they are greyish or brownish sandy topsoils resting on pumice gravels.

(3) *Gley soils* (or meadow soils). Gley soils are formed on swamplands where drainage is slow, e.g., on the Hauraki Plains.

(4) *Peat Soils* (or organic soils) occur on W. Hauraki Plains and the lower Waikato plains and other places where the soils have been permanently wet for long periods.

(5) *Yellow-brown loams* of Waikato and Taranaki. The topsoils are brown in colour, very friable in texture and with a granular structure. The subsoils are yellow-brown or brown and fairly friable, e.g., Ohaupo silt loam, Tirau silt loam, Egmont silt loam.

(6) *Red-brown loams* are formed on the old lava flows near Auckland City and in Northland.

C. AZONAL: Those soils which are too young for soil-forming processes to have had much effect.

(1) *Skeletal soils.* These are the shallow soils of the steep hill country and make up over 50 per cent of the occupied land of New Zealand. They vary in fertility according to the composition of the parent rock and the steepness of the land. Where developed from calcareous sandstones and mudstones, e.g., papa rock, well supplied with minerals, they are fertile and slips heal over readily. Where the slopes are greater than 30°, erosion of farming land is likely to be a major problem. Most of this latter sort of country should be in forest to keep it more stable than it would be in pasture.

(2) *Recent soils.* These are of two kinds: (a) Alluvial soils formed by rivers, e.g., Waikato, Manawatu, Clutha; (b) Volcanic soils formed from eruptions by Mt. Tarawera and Mt. Ngauruhoe.

MAN'S INTERFERENCE IN SOIL FORMATION

The process of podzol forming, podzolisation, can be arrested and to some extent reversed by farming practices such as:—subsoiling to break up iron pans causing bad drainage and water-logging; heavy initial liming followed by annual or biennial light liming to reduce acidity and to maintain correct acidity; the regular addition of fertilisers containing minerals essential to plant growth, notably phosphate and potash; cultivation to mix the upper podzol horizons; the introduction of earthworms to help to distribute the organic matter and to promote drainage and aeration; the growing of deep-rooted plants to gain minerals from the lower horizons; and tile draining and mole draining. By such practices podzols, provided they are not the most developed forms, may be turned into soils resembling somewhat the yellow-brown earths.

If the soil has a high water-table during several months of the year, there develops a profile of what is called a *gley soil* (or meadow soil). Typically there is a surface horizon rich in organic matter, greyish-brown in colour and crumbly in structure; then there is a brown coarse blocky horizon followed by the gley horizon which is grey in colour mottled with rust colours and perhaps containing concretions of ironstone or other substances. The largest area of gley soils in New Zealand is on the Hauraki Plains.

In order to farm these soils properly they must first be well drained and then they will carry good pastures. During the winter the soil drainage cannot cope with the high rainfall so that stock tend to poach the soil leading to the invasion by weeds such as buttercup and rushes. To avoid this, farmers, as far as possible, winter their stock on higher ground nearby.

Permanent water-logging of a soil causes organic matter to accumulate because, owing to the lack of air (the anaerobic state), decomposition is very slow. Such organic deposits are formed in hollows or on low-lying flats and vary considerably in composition according to the amount of mineral particles washed into them, to the original plant cover, and to the depth of accumulation. They are called *peat soils* (or organic soils). Large areas of peats occur in the lower Waikato and on the Hauraki Plains. Broadly speaking, the deeper the peat the more acid it tends to be and the more difficult it is to farm. Ordinary drainage is not good enough for deep peats. They can easily be overdrained so that in the summer the peat dries, is not easily re-wetted, and crops and pasture fail because of drought. Moreover fires easily start in dry peat, are difficult to control, and may burn the soil to a level below its outfall so that it cannot be drained again. Methods of levelling and draining allowing for return of water in dry weather are needed. On most peat soils in New Zealand heavy initial liming, mixing the lime deeply into the soil, and the application of copperised phosphate and potash fertilisers are needed to produce good pastures and farm and vegetable crops. There are about 100,000 acres of deep peat in New Zealand.

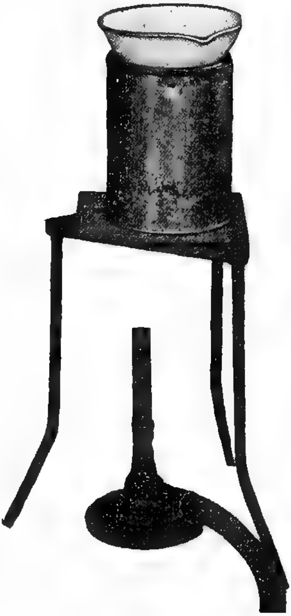


FIG. 49. A home-made water bath for drying soil

ESTIMATION OF ORGANIC MATTER AND FREE LIME

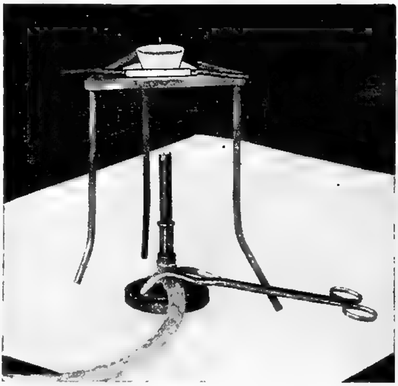


FIG. 50. Igniting a sample of soil

It is an interesting exercise to estimate the amount of organic matter in peats and other soils. If you have no peat soil in your district, you may perhaps arrange an exchange of soil samples from your district with those, including peat, from a district which has peat soil. Consult soil maps and maps showing towns.

The total organic matter is estimated by igniting a sample of dry soil. The loss in weight represents rather more than the total organic matter, and is therefore referred to as *loss on ignition.*

Exercise 4.—Dry a small quantity of pulverised soil over a water-bath for half-an-hour (Fig. 49). Obtain a clean porcelain crucible and heat for ten minutes over the bunsen flame; cool and weigh. Weigh into the crucible about one gram of the dry soil, and ignite over the bunsen burner for half-an-hour (Fig. 50). To allow complete combustion of the organic matter the lid should be removed. When all the organic matter appears to have been burnt out, cool and weigh. Again ignite for 10 minutes, and cool and weigh. Continue burning and weighing till a constant weight is obtained, at which point, we can suppose that all the organic matter has been burnt out. Tabulate the results as follows:—

ESTIMATION OF LOSS ON IGNITION

	Soil:—Light loam, in grass for 4 years.	grams.
Line 1.	Weight of crucible	12.56
Line 2.	Weight of crucible and dry soil ..	15.78
Line 3.	Weight of dry soil (line 2 – line 1) ..	3.22
	After burning for 20 minutes and 10 minutes	
Line 4.	Weight of crucible and burnt soil	15.39
Line 5.	Loss in weight (line 2 – line 4)	.39
Line 6.	Percentage loss on ignition	

$$\frac{\text{line } 5 \times 100}{\text{line } 3} = \frac{.39 \times 100}{3.22} = 12.11\%$$

A rough test for the detection of free limestone in the soil can be carried out, making use of the fact that when hydrochloric acid is poured on either carbonates or bicarbonates there is immediately an evolution of carbon dioxide accompanied by effervescence.

Exercise 5.—Obtain samples of several different soils. Take equal quantities of each, and treat each soil in a test-tube with hydrochloric acid. Distinct effervescence indicates that the soil contains about 1 per cent or more of carbonate of lime.

THE ORIGIN OF SOME RECENT AND YOUNG SOILS

(a) *Recent Soils from Alluvium.* These are amongst the richest of the agricultural lands. During heavy rain a great deal of soil, together with organic matter, is washed into the creeks and rivers. The rapid flow of the river at this time enables the water to carry a great deal of this material in suspension. When the river is again normal and the flow reduced this suspended matter gradually settles. Coarse material, as sand, is deposited first, and is followed by the silt, clay, and organic matter. In many cases, however, the banks are low, and the water rising above these is spread in a sheet over the flat country through which the river is passing. The water which, until now, has been flowing rapidly, comes almost to a standstill, and the suspended matter soon sinks. Finally the sheet of water either percolates through the soil or flows slowly back again to the river, in either case leaving behind it a layer of silt. Repeated occurrences of this kind have resulted in the formation of very rich and deep alluvial soils. Their richness is due to their high content of phosphorus and potassium and to the fact that their humus is found to a much greater depth below the surface than is usual in other soils. The *texture* of these soils, that is, the relative proportion of fine grains to coarse grains present, will depend upon the speed with which the water was flowing when the particles settled. Thus alluvial soils may show variations in texture within a very limited area. For the same reason the upper reaches of a river may produce coarser-grained soils than the lower reaches, where the flow is not so rapid, and a greater proportion of the silt and clay settles.

An examination of the soil on a farm situated on the banks of a river subject to floods, will, in normal cases, demonstrate that the flow is reduced as the sheet of water stretches further from the river. This allows the silt and clay to settle, and the resultant soil is fine grained. Near the banks, where the flow is comparatively rapid, the soil contains a greater proportion of sand and a lesser proportion of clay. Many variations to this will be found, but they can usually be accounted for by an examination of the river while in flood.

(b) *Young Soils from Volcanic Ash.* Over most of the central North Island in the Rotorua-Taupo region and extending to the Bay of Plenty and to the Gisborne district soils have been formed from young deposits of rhyolitic pumice thrown out by volcanic eruptions. These deposits have been classified into the following ash-showers:—Tarawera, Ngauruhoe, Kaharoa, Taupo, Egmont, Tongariro, Tirau, and Mairoa. Each shower gives rise to separate groups of soils. Those soils from rhyolitic pumice showers such as Kaharoa and Taupo are called *yellow-brown pumice soils.* Those from fine volcanic dust of andesitic and rhyolitic composition such as Egmont, Tongariro, Tirau, and Mairoa showers are called *yellow-brown loams.* In South Auckland and North Auckland districts volcanic ash and basaltic lava are the original materials of several brown soils, notably the *brown granular loams and clays* and the *red-brown loams.*

(c) *Soils from Loess.* The wind has always been an agent in soil formation and soil transportation. Probably all soils contain some wind-formed or wind-borne particles. In certain cases the wind has been the dominant agent in the formation of a soil. Wind-borne material from rivers fed by glaciers is called *loess,* and is exemplified extensively in China, where there occur beds of great surface extent and of depths ranging up to 2,000 feet. In New Zealand loess deposits occur in Canterbury, Otago and Southland. Fine silts borne along by glacial streams from the Southern Alps, were spread over wide beds in times of floods. As the waters withdrew the silts dried in the sun, and were then picked up by the north-west winds and carried to the plains where they were caught by the vegetation, and gradually accumulated. The soils formed from this loess are classified mainly as *yellow-grey earths.* They form tracts of rich land in Canterbury. The deposition has been extensive, for in places, e.g., Banks Peninsula, the loess soil is 30 feet deep. The fertility generally possessed by loess soil is due partly to the fine particles of which it consists, and partly to the slow leaching of minerals under the sub-humid climate of Canterbury.

READING

Rural Education Bulletins, Mar., Apr., Aug., 1946
Canterbury Chamber of Commerce, Agric. Bulletin, Sept., 1954
Massey Agric. College, *Sheepfarming Annual,* 1949
N.Z. Journal of Agriculture, Oct. 1955, p. 352
Good Soil (Chapters 1-6), Brade-Birks, S. G.
Elements of Agriculture (pp. 1-21), Fream
Post-Primary School Bulletin, Vol. 1, No. 22
N.Z. Department of Agriculture, Bulletin No. 279
D.S.I.R. General Survey of the Soils of North Island, N.Z.

FILMS

(The National Film Library)
'Making of the Soil'
'Birth of the Soil'
'Formation of Soil'
'Our Soil Resources'

9

Soil Texture

WHEN cultivating his soil a farmer describes it as heavy or light. Soils that take much tractor power and give great resistance to ploughing are called heavy soils and those with small resistance are called light soils. Heavy soils are *clays,* intermediate soils are *loams*, and light soils are *sandy soils.* This property of a soil which chiefly determines its ease of working is called *soil texture.* It is a very important property of the surface soil for it largely determines the relation of the soil to farming, as, for example, the kind of crops which can be grown to best advantage and the liming and the fertilising required. The texture of a soil depends upon the sizes of the mineral particles present and upon the relative amounts of the various sizes.

The following groups of particles may contribute in varying proportion to the mineral portion of a soil:—Stones, gravel, sand, silt and clay. Mixed with these mineral particles is a variable quantity of decaying organic matter, normally present in largest amount in the surface layer of the soil. These fractions seem simple enough in themselves, but they are present in such varying proportions that the soils they form exhibit almost endless variations.

Sand is produced largely from the physical disintegration of rocks mainly quartz (crystalline silica). The grains vary in size, but even the finest are comparatively large in proportion to the size of clay particles. The presence of sand makes the soil very porous and well aerated. Silica contains no essential plant food, and nearly all sandy soils are poor in this respect. They contain very little humus, because they allow free percolation of air to oxidise the organic matter.

Silt is derived mainly from quartz and felspars. The particles are intermediate in size between those of sand and clay.

Clay is extremely fine in texture, and represents the product of weathering of felspars and other minerals. Clay is characterised by its plastic nature when worked up or puddled with water. In this state it is quite impervious to air and water, and on drying will retain any shape into which it is worked while wet. While drying, however, a considerable amount of shrinkage takes place (Fig. 51), and it is common to see the hard surface of clay soils crack during dry weather.

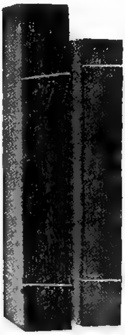


FIG. 51. Showing shrinkage of clay. The block of wood on the left represents the size of the original clay.

Clay before drying: 19 x 2.8 x 2.8 cm.
Clay after drying: 16.5 x 2.2 x 2.2 cm.
Volume before drying: 148.96 cu. cm.
Volume after drying: 79.86 cu. cm.
Shrinkage: 69.1 cu. cm. = 46.3 per cent

Exercise 1.—Obtain some fine clay, and after it has been thoroughly puddled with water, make it into a brick about 6 inches long and 1 square inch in section. Place by the side of the clay a piece of wood of the same dimensions. Allow the clay to dry for about a fortnight, and observe the shrinkage by comparing it at intervals with the piece of wood (Fig. 51).

Exercise 2.—To compare the effect of drying on (a) puddled clay and (b) puddled sand. Knead up a little clay into a plastic state with water and press enough into a crucible lid or similar container to fill level. Proceed similarly with sand as far as it is possible to do so. Leave both sets of containers for a few days to dry. Then note the differences between the clay and the sand and explain.

Exercise 3.—Take some of the dry puddled clay from the previous experiment and divide it into two lots. Heat one lot strongly to red heat and then leave it to cool. After grinding up both lots separately, try to mould each lot with a little water. Which lot will not mould? Explain.

Exercise 4.—Obtaining two crucibles of similar size fill the one level with dry, powdered clay and the other level with dry sand. Immerse both crucibles simultaneously in still water held in a glass trough. Note first [illegible]es at which each crucible loses air and second what happens [illegible]rther properties has clay that sand has not? Make a sketch of the apparatus as it appears twenty minutes after it was set up.

COLLOIDAL CLAY—

The clay includes all particles less than .002 mm. in diameter, but if we study those which are less than .001 mm. in diameter we shall find they are very important to the fertility of the soil. Such small particles are called *clay colloids.* The colloids are crystalline and consist chiefly of silica combined with alumina and water. To the crystals are loosely held ions of hydrogen, calcium, magnesium and potassium. Colloids with a high percentage of hydrogen give to the soil an undesirably high acidity which can be reduced by adding lime to the soil. The calcium from the lime attaches itself on to the clay crystal by displacing some of the hydrogen, thus lessening the acidity.

When potassium salts are added to the soil some of the potassium displaces hydrogen and fixes itself on to the clay, thus becoming held more efficiently against leaching. The plants can take away from the clay the potassium as they need it. On the other hand dressings of ammonium sulphate displace calcium and add hydrogen to the clay, making the soil acid, and this is, as is well known, overcome by liming to increase again the calcium in the clay. In soils which have been flooded for long periods with sea water, sodium displaces the calcium in the clay and the soils become unsuitable for most agricultural crops. To remedy the defect, after removal of the salt water, gypsum (calcium sulphate) is applied to the soil to convert the clay back into a calcium clay. The addition to clay colloids of cations or bases, e.g., calcium, and the subtraction of cations (bases) from these colloids is known as *cation* (*base*) *exchange*. (See Chapter 11.)

FLOCCULATION

The peculiar properties of clay are dependent on the fineness of its grains. Clay is most plastic when thoroughly puddled, the particles being individually distinct. If, however, a number of these particles are caused to join together to form larger aggregates, the soil will then lose, to some extent, its plastic nature and become more friable and open. Water in which a little clay has been rubbed usually remains turbid for a couple of days owing to the fineness of the individual clay particles. If a little burnt lime be added a change is perceptible almost immediately. (Fig. 52.) Large 'flocks' are formed, and the soil which has thus become *flocculated* sinks rapidly to the bottom (Fig. 52). If, on the other hand, a little caustic soda or ammonia be added, the clay becomes dispersed into its ultimate particles, and in this *deflocculated* condition will remain in suspension for days and weeks.

Exercise 5.—In a large vessel work up some well-puddled clay till the water becomes turbid. Fill several glass jars or test-tubes with the liquid, and test the effect of the following substances in flocculating or in deflocculating the clay.—Quick-lime or limewater, hydrochloric acid, and caustic soda (Fig. 52). It will be necessary to retain at least one jar of the original liquid as a control. The vessels used must be perfectly clean, otherwise the results may become very misleading.

A flocculated condition is very desirable in a clay soil and the beneficial effect of lime on the physical properties of clay soils was formerly attributed to a flocculation effect. It is apparent from Fig. 52, however, that both acid and lime are equally effective in promoting flocculation so that the simple flocculation theory cannot account for the improvement in physical properties of acid soils following the addition of lime; this point is dealt with later in Chapter 11.

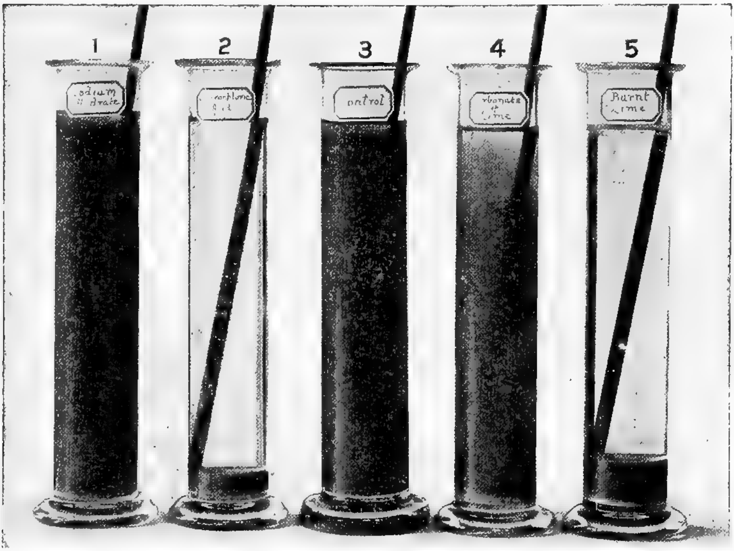


FIG. 52. Flocculation of clay. Jars have been treated as indicated by labels

FIG. 52 Flocc
FIG. 52 Flocc
FIG. 52 Flocc

Humus is the product of the decomposition of organic matter. The term is sometimes incorrectly used when making reference to the total organic matter in the soil; true humus consists of that part of the organic matter in a very advanced stage of decomposition. It is dark brown in colour, and imparts this property to the soil. The proportion present in mineral soils is frequently a reliable guide to the fertility of the land, and in sound farming practice, especially in dry areas, every endeavour is made to maintain, or even increase, the amount present in the soil. Under constant cropping and tillage the humus is rapidly used up unless due allowance is made for its restitution.

The improvement effected in both sand and clay by incorporating organic matter is very marked. Since humus is capable of holding nearly double its weight of moisture it acts in much the same way as a sponge. Chiefly to this fact, and to a lesser extent the plant food liberated by humus on decomposition, must be attributed its ability to increase the fertility of sandy soils. In a clay it ameliorates the plastic properties, and renders the soil more friable and pervious to water. Peat is unlike humus in that it consists of organic matter which, owing largely to lack of air, has not been able to decompose very far, and thus remains in a preserved condition. (See Chapter 12.)

A rough but ready method of determining the relative proportion of humus present in two or three samples of soil can be carried out by extracting the humus present by a solution of either caustic potash or caustic soda.

Exercise 6.—Obtain small samples (about as much as will cover a sixpenny piece), of the various soils to be tested. Place each in an evaporating dish, half fill the dish with a solution of caustic potash. Boil each for a few minutes, add an equal quantity of cold water, and filter. Catch the filtrates in test-tubes and compare the colours. The deeper the colour the larger is the percentage of humus extracted from the soil.

CLASSIFICATION OF SOILS ACCORDING TO COMPOSITION

The proportion of sand, clay, and humus present in the soil has a marked effect on its general character. A hand and eye test will enable an experienced person to judge approximately the proportion of each ingredient present. Soils may be classified according to their texture into many divisions, but the principal ones used on soil surveys are:—

Sands.—Sand, 80 to 90 per cent; clay and silt total 10 to 20 per cent.

Sandy Loam.—Sand, more than 60 per cent; clay and silt totalling from 20 to 40 per cent.

Loam.—More than 40 per cent silt and clay combined; less than 25 per cent silt and less than 50 per cent sand.

Silt Loam.—More than 40 per cent silt and clay combined, and less than 50 per cent sand.

Clay Loam.—Silt and clay combined exceeds 50 per cent and clay less than 25 per cent.

Clay.—Silt and clay combined exceeds 50 per cent and clay more than 35 per cent.

Gravelly soils contain 15 per cent and over of gravel, with particles more than 2 mm. in diameter.

Calcareous soils contain 5 per cent and over of lime.

Peaty soils contain 35 per cent and over of organic matter.

CLASSIFICATION OF SOIL ACCORDING TO TEXTURE

Soil texture can be classified simply and quickly yet accurately by experienced people following a method invented by Milton Whitney, a soil surveyor of the United States of America. By handling and examining samples of a soil a trained person can assign the soil to various textural classes.

The following notes and diagrams on handling and technique have been taken from the book, entilted, *Good Soil,** with modifications suggested by the Soil Bureau, N.Z. Department of Scientific and Industrial Research.

Pick up a handful of moist but not wet soil, and mould the whole handful with your fingers. Is is gritty? If so, you are conscious of the presence of sand grains. If it is not gritty, is it sticky? If so, that stickiness is due to clay. But perhaps it is neither sticky nor gritty, but has, instead, a feeling best described as silky—like the handling of a silk handkerchief. In such a case silt preponderates.

Sand, silt and clay are three *grades* of mineral materials and they differ from one another in the size of the individual particles of which they are composed.

Of these three grades, two, viz.: silt and clay, the silky and the sticky grades, need no sub-division; but with the other grade, sand, it is convenient to recognise two sizes of individual grain. Perhaps when you speak of sand, you visualise some familiar sea-shore sand, and it is quite likely that the particles are about the size of these dots : . : This is medium sand; any sand coarser than this is *coarse sand*, the particles of which are between one millimetre and half-a-millimetre in diameter. Sand with smaller grains than those of medium sand is *fine sand.*

TECHNIQUE OF DETERMINING THE TEXTURE

From the surface of the ground take up a handful of the soil in a moist (not wet) condition, mould it with the whole hand and ask yourself three questions, or as many of them as may be necessary.

---

* *Good Soil,* by Brade-Birks, pp. 140-2, 151-5.

The first question: Is the soil gritty? By gritty is meant that sensation which is experienced when a handful of sand, such as sea-shore sand, is kneaded between the palm and fingers. Let us, in the first instance, presume the answer is in the negative. Then let us pass to:

The second question: Is the soil silky? (i.e., has the soil the feeling that is imparted by handling silk fabric?) Again, presuming 'No' to be the answer, we ask:

The third question: Is the soil sticky? For the third time we shall presume that the answer is in the negative.

Thus, from our answers to three questions we have arrived at the conclusion that if the soil is devoid of grittiness, silkiness and stickiness, there is one soil class, and one only, that gives this result on handling, and that soil is *loam*.

To return to *the first question*: Is the soil gritty? If our answer be 'yes', the soil is lighter in texture than loam.

If the grains are clearly visible we recognise the soil as No. 1, *Coarse Sand*.

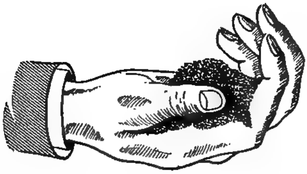


FIG. 53. Soil texture. Testing a handful of soil for grittiness, silkiness and stickiness

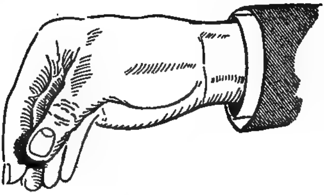


FIG. 54. Soil texture—polish. Pressing a small quantity of moist soil with a sliding motion between fingers and thumb to see if a polish can be induced

If the individual grains are just visible individually to the naked eye, we are dealing with a soil which we classify as No. 2, *Fine Sand*.

Having dealt with those two classes in which there is no soiling of the fingers on handling a sample, we now consider those gritty soils which do soil the fingers. Among these, some can be moulded into a cohesive ball, some cannot. If the sample soils our fingers, but we cannot get it to form a cohesive ball, the soil is called No. 3, *Loamy Sand*.

Gritty soils which can be moulded into a cohesive ball when just moist, belong to the group of textures called sandy loams:—

4. Coarse sandy loam.
5. Sandy loam.
6. Fine sandy loam.

When the sample soils the fingers, is cohesive and has an obvious silky feeling and is about ready to take a polish, the soil is No. 7, *Silt Loam.*

When a definite polish can be produced by pressing a sample in a moist, but not wet, condition between the thumb and forefinger, the soil contains an appreciable amount of clay, and when resistance to moulding, while considerable, can be overcome without difficulty, the soil is No. 8, *Silty Clay Loam.*

Resistance to deformation begins to be difficult with No. 9, *Clay Loam.* This resistance gradually increases with increased proportion of clay particles, and when resistance to deformation between the finger and thumb becomes difficult the texture may be called No. 10, *Clay.*

SOIL SURVEYING

With soil varying from place to place, farm to farm, paddock to paddock, and from one part of a paddock to another, it is essential, if the best is to be obtained from the soils, to study them systematically and to classify them. Farming carried on by trial and error improves only slowly, incurs many costly mistakes, and tends to become confined to naturally fertile soils. Modern classification of soils started about the year 1900, following the outstanding work by Russian soil scientists in the latter part of the 19th century, and the application of the results of this work to soil problems in the United States of America.

Soil surveyors or pedologists study the soils in a district and record the distribution of each type of soil on a map. Then soil chemists, soil physicists, and soil biologists study these types to get all the information they can about them. At the same time agricultural scientists and farm advisers collect all the available farming information about each soil type. All this information along with the maps is published as a *soil survey bulletin* for the use of all who are interested.

In the words* of Dr. C. E. Kellog, Chief of the United States Soil Survey, 'The primary objective of the Soil Survey is to define kinds of soil in such ways that our knowledge about soil behaviour and farming systems can be organised and presented to farmers so that they can work out the best combination of practices for their own fields.'

Soil surveying and soil science is carried out in New Zealand chiefly by the Soil Bureau of the Department of Scientific and Industrial Research.

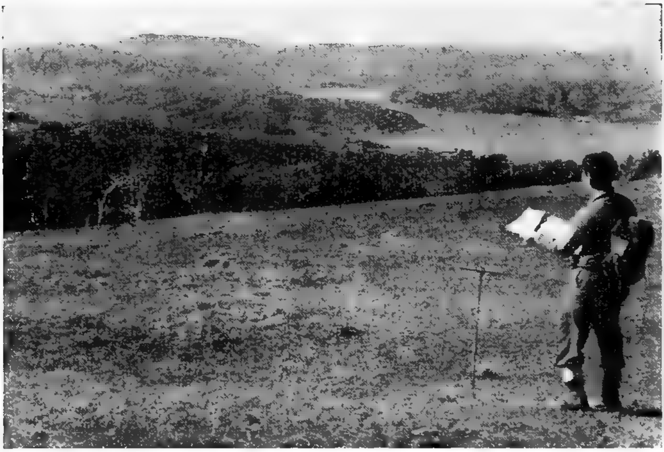


FIG. 55. Carrying out a soil survey near Wellington (*Soil Bureau*)

PREPARING A SOIL SURVEY MAP

A pedologist working in a certain district has with him a map of the district prepared by ordinary land surveyors or by geological surveyors or from aerial photographs. Other equipment he carries includes: a compass, a chain tape, a soil auger, a spade, a bag for samples and a notebook. First he examines the soil profiles wherever available in such places as road cuttings, slips and creek banks to get a general idea of the kinds of profiles in the district. Then he selects sites to dig holes to examine profiles and each area is checked for soil profile similarity by boring down 3 or 4 feet with the auger at regular intervals in definite directions. The textures of the top soils throughout the area are assessed by handling and noted. Sections of similar surface texture are defined and their boundaries drawn on the map. By sorting these profiles he defines areas within which the soil profiles are closely similar. In each such area he selects a representative profile, describes each horizon in it for colour, texture and structure and takes samples from each horizon for physical, chemical and biological tests in the laboratory.

---

* Quoted from 'Rural Education Bulletin', April 1957, and taken from the *American Journal of Soil and Water Conservation.*

How close the sampling of the profiles and of the top soils is done depends upon: (1) the intensity of the farming in the district, e.g., market gardening needs intensive sampling and sheep farming extensive sampling, and (2) whether or not a special problem is being studied in a particular area such as farm management in relation to soil type.

NAMING SOILS

Soils having similar profiles are grouped together and called a *soil type* which is given a name such as Hamilton clay loam. The first part of the name refers to a locality where the soil occurs and the second part refers to the texture of the topsoil. Other types are, for example, Horotiu sand and Horotiu sandy loam in the Waikato; Paki Paki clay loam and Paki Paki coarse sandy loam in Hawkes Bay; and Lincoln silt loam. Closely-related soils from the same parent material are grouped together as *soil suites* and these may be combined to form *soil groups* which can be fitted into the soil groups of the world, e.g., podzols, yellow-brown earths, rendzinas. (See New Zealand Soil Map.)

VALUE OF SOIL SURVEYING

New Zealand, with its very high proportion of rough hilly country, with few areas having anything but shallow soils, has special need of the very best that soil surveys and scientific investigation into soil can provide. It is the work of soil scientists to find out all they can about soils and to map them accurately and to revise them constantly. So soil survey maps become the most detailed of all maps and can be used by many kinds of people. The soil map is the key map from which special maps can be produced of use to other scientists, farmers, land valuers and engineers.

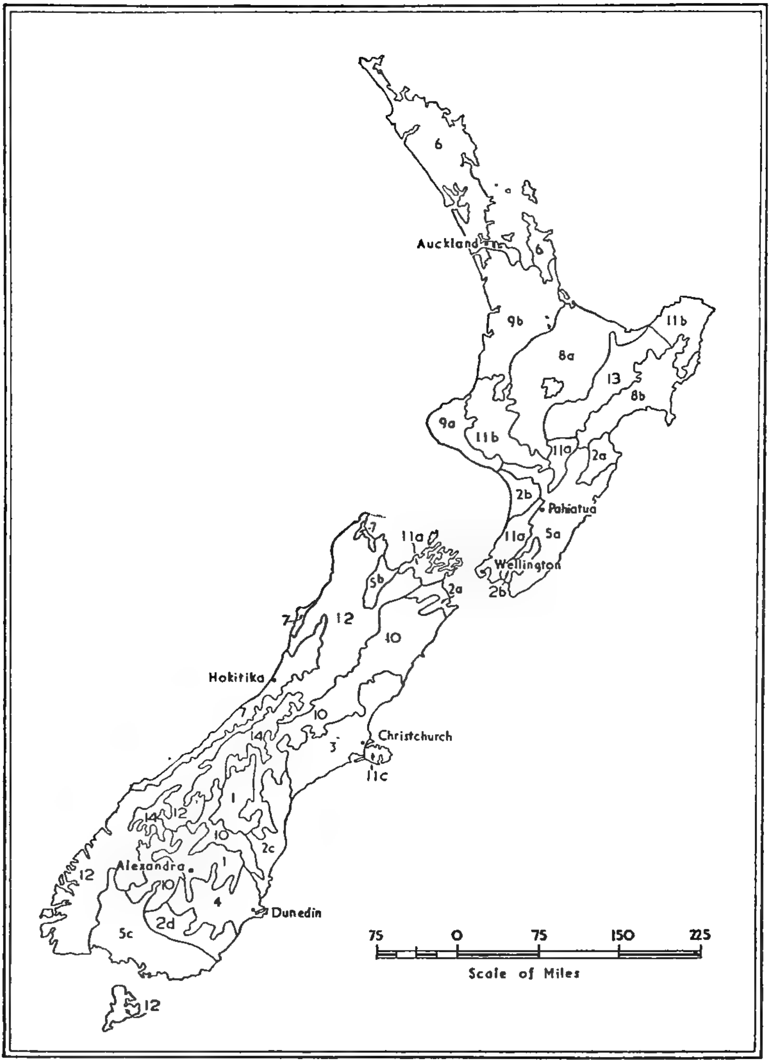


FIG. 56. Soil Map of New Zealand (*Soil Bureau*)

LEGEND, FIG. 56

NOTE: Only the more important soils in each association are named in this legend.

Brown-grey earths	
—with related steepland soils	1
Yellow-grey earths	
—with recent soils, and steepland yellow-grey soils	2a
—with yellow-brown sands, and recent soils	2b
—with related soils on gravels, and rendzinas	2c
—with yellow-brown earths*, and recent soils	2d
Stony soils on gravels, related to yellow-grey earths	
—with yellow-grey earths and related steepland soils, recent, and gley soils	3
Yellow-brown earths, weakly weathered	
—with yellow-brown earths* and related steepland soils	4
Yellow-brown earths, moderately weathered	
—with related steepland soils, and yellow-brown loams	5a
—with recent soils	5b
—with podzols, soils related to yellow-brown loams, gley, and organic soils	5c
Yellow-brown earths, strongly weathered	
—with podzols, brown granular clays and related steepland soils, red-brown loams, rendzinas, yellow-brown sands, gley, and organic soils	6
Gley podzols	
—with yellow-brown earths*, recent, and gley soils	7
Yellow-brown pumice soils	
—with related steepland soils, recent soils (from volcanic ash), and yellow-brown loams	8a
—with yellow-brown earths* and related steepland soils, yellow-brown loams, and recent soils	8b
Yellow-brown loams	
—with gley soils	9a
—with yellow-brown earths*, brown granular clays, gley, and organic soils	9b
Steepland yellow-brown soils†, weakly and moderately weathering	
—with yellow-brown earths, weakly and moderately weathered	10
Steepland yellow-brown soils†, moderately weathering	
—with yellow-brown earths*	11a
—with steepland yellow-brown loams, and yellow-brown earths*	11b
—with steepland brown granular soils and yellow-grey earths	11c
Podzolized steepland soils†, weakly and very weakly weathering	
—with mountain soils, bare rock, and ice	12
Steepland yellow-brown pumice soils	
—with steepland yellow-brown soils†, moderately weathering	13
Mountain soils, bare rock, and ice	14

* Moderately weathered.

† Related to yellow-brown earths.

Recent soils are from alluvium unless otherwise indicated.

Agricultural scientists and farmers use special soil maps chiefly as follows:—

(1) Farm management practices such as topdressing can be determined, because, in general, the results obtained on one particular soil type of a farm or a paddock can be obtained on other farms or paddocks of the same soil type.

(2) Problem soils, such as the cobalt deficient pumice soils of the Central Plateau of the North Island and the ironstone soils of Northland, can be related to soil type and so farmers know where to expect these soils and to be prepared to deal with them.

(3) Some trace element deficiencies in soils can be related to the amount of leaching suffered by the soil, i.e., they can be related to the suites of soils. It is possible that only the more mature suites of a soil in a district prove to be deficient in a trace element.

(4) As certain crops are known to be suited to certain soil types, e.g., tobacco, linen flax, apples, then the extension of the areas of these crops can be guided by consulting soil maps.

(5) Farming problems can often be related to the great soil groups of the world. For instance, the means taken to overcome difficulties on, say, podzols in England may be useful on difficult podzols in New Zealand; the means of production of useful crops on peat in U.S.A., may show the way to similar production on peat in New Zealand.

Other uses to which soil maps may be put are:—

(1) Defining where soil erosion may be expected and so perhaps prevented, and, if the soil erosion is proceeding, deciding where it is likely to be arrested.

(2) In preparing land for a large irrigation scheme. Knowing the soils enables problems to be anticipated and costly mistakes avoided.

(3) Deciding what kinds of foundations are necessary for buildings, airfield runways, and roads.

(4) Assessing the suitability of soils for water-storage dams.

Exercise 7.—Make a copy of a soil map of your district. For each type of soil on the map, note: The type of farming carried on with reasons, the kind of stock carried and the carrying capacity developed and undeveloped, pasture type, fertilising, liming, weeds and their control, pasture management generally, drainage, production per acre of butterfat, or of meat and wool. Consult your local instructor in agriculture or farm adviser for help.

READING

Good Soil, (Chapters 7-10), Brade-Birks

General Survey of the Soils of the North Island, N.Z., D.S.I.R.

Rural Education Bulletins, June & Aug., 1946 and Apr., 1957

Cant. Chamber of Commerce Agric. Bulletin, No. 302

Soils and Manures in New Zealand, Wild, Chapters 1 & 5

Massey Agricultural College Sheepfarming Annual, 1949

Post-Primary School Bulletin, Vol. 1, No. 22.

10

The Physical Properties of the Soil

BESIDES soil texture, which has been considered fully in Chapter 9, there are several other physical properties of soils which are important in farming.

SOIL STRUCTURE

This is a property entirely different from soil texture. It is the state of a soil where the particles are grouped together more or less loosely as aggregates. This state has a marked bearing on soil fertility. In soil having a fair proportion of humus and lime the soil grains are not present as individual particles but are grouped together as aggregates. With this grouping the soil has better air and water conditions than if the soil is in single particles.

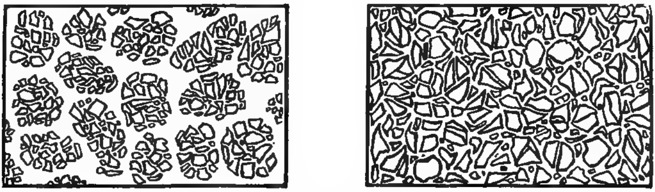


FIG. 57. *Left*: Granulated soil showing maximum pore space; *Right*: Soil not granulated showing minimum pore space

Exercise 1.—Spread some friable soil on a sheet of white paper, and examine with a hand lens or a low power microscope. Pick out a single granule and see if it is not possible to break it up into a number of grains by a little pressure from the point of a knife.

The structure of a soil is named after the term given to the aggregates. Soils with cube-like or sphere-like aggregates—2 mm. to 5 mm. in size—have a granular structure; those with fragments between 5 mm. and 20 mm., crumb structure; and those between 20 mm. and 50 mm., clod structure. Light sandy soils with little or no clay are spoken of as having a single grain structure. Most New Zealand soils possess a crumb structure.

By means of sieves the aggregates can be graded according to size. The table below shows the composition of a Wellington alluvial soil consisting chiefly of crumbs and granules:—

Percentage retained on sieves			Percentage passed by sieve
6 mm.	3 mm.	2 mm.	2 mm.
49	27	6	18

Decomposing organic matter acts as the cementing agent of the aggregates, and it is for this reason that soils have a better structure under pasture, which gives much organic matter by the decay of roots, than under continuous cultivation. If the soil is constantly under cultivation then green crops, when ploughed in, help to maintain the soil structure.

The soil structure determines the *tilth* which can be obtained on cultivation. Coarse aggregates make a coarse tilth and fine ones a fine tilth. Probably all plants require a certain size of crumb for optimum growth. When the tilth is right the plant obtains sufficient moisture and bacterial activity is at its best. The aggregates are by no means indestructible and care must be taken in handling the soil. If it is worked when too wet it poaches and dries out in hard clods, whereas if it is too dry then some of the aggregates are broken up and too fine a tilth obtained.

Clods and lumps in a soil can be broken down to crumbs by weathering in two main ways. During the winter, moisture inside a lump of soil expands on freezing and many repetitions of this result in the lump being broken down. It can be seen that this is so by observing a Canterbury wheat field in the winter just after sowing and then again when the wheat is a few inches high in the spring. Clods brought to the surface by cultivation prior to winter sowing are replaced by crumbs in the spring. The other main method of conversion of clods to crumbs by weathering occurs in the summer. It is by repeated alternate wetting and drying. When a lump of puddled clay dries, air enters it; on re-wetting, the air inside becomes compressed causing the lump to crack. Many repetitions of wetting and drying result in the reduction of a cloddy surface soil to a good tilth. This is one of the reasons for summer fallowing. (See more about Fallowing in Chapter 15.)

Tilth is not quite the same thing as structure. Tilth can be worked up in a soil by cultivation but it will not last long unless there is enough organic matter in the soil. Without sufficient organic matter the tilth of a soil is easily destroyed by the first heavy fall of rain which breaks up the crumbs and forms a crust on the surface of the soil. This crust cracks on drying and germination is retarded.

Good crumb structure of a stable nature in a soil is important too in *soil conservation*. Under conditions of heavy rain or high winds, fine soil particles are readily washed away or blown away. If the soil particles are bound together into heavier crumbs, such as commonly occurs under good pasture, the soil then tends to be conserved. (See Chapter 16.)

SYNTHETIC SOIL CONDITIONERS

Under arable conditions, as contrasted with pasture conditions, organic matter is continually being lost. In many soils, along with this loss of organic matter, goes the breakdown of the crumb structure of the soil and tilth cannot be maintained. It has been shown that certain gummy substances in the organic matter are responsible for the good structure the organic matter produces. Artificial gums, such as Krilium, Merloam, and Flotal have been produced to improve the structure of heavy soils in the same way as the natural gums. At present these synthetic soil conditioners are too expensive to use except in such places as glasshouses and seed-beds.

PORE SPACE

Pore Space refers to the space occupied in a dry soil by air. The amount of space is to a large extent determined by the state of granulation and the extent to which the soil has been packed. Given a condition in which all the soil particles are of uniform size, then mathematically the size of the grains will not influence the total amount of pore space. A bucket, whether full of large or small shot, will hold approximately the same amount of water. By carrying out actual trials, however, it is evident that there is a marked difference between the pore space of different soils. The reason is two-fold:—

(1) In a granulated soil such as is shown in Fig. 57 pore space exists not only between the individual soil particles but to a large extent exists also between the granules. In a soil of this type we can expect to obtain maximum pore space.

(2) Large coarse grains are individually heavier than fine particles of clay and silt. They are, therefore, capable of settling and packing more firmly, and the amount of pore space is correspondingly reduced. This fact can be readily shown by measuring the amount of sand and clay respectively that can be poured into a given volume of water till the soil and water are on the same level.

Exercise 2.—Procure two measuring cylinders each containing 50 ml. of water. Pour slowly into one dry sand, and into the other finely pulverised clay till the soil and water in each case are on the same level. If we now take the reading of the volume of soil, we can argue that this volume of soil is capable of holding 50 ml. of water, and therefore has this volume of pore space. From this calculate the percentage of pore space. The results obtained will be valuable for comparative purposes only, and will not necessarily indicate the actual pore space of the soil under natural conditions. That the difference observed is not due directly to the size of the soil grains can be proved by repeating the same experiment, using gravel and lead shot which have been sieved till the individual grains are as nearly as possible of the same size. The lead being heavy and smooth packs more readily, and will show from 10 to 20 per cent lower pore space than the gravel.

WEIGHT OF SOIL

The reference made by farmers to heavy and light soils is somewhat misleading when we come to consider the difference between the weights of equal volumes of sand and clay, that is their relative weights. In reality sand, which is referred to as light, is heavier than clay. The terms heavy and light do not then refer to the actual weight, but to the draft of the plough, or the resistance the soil offers to tillage operations.

Exercise 3.—To determine the relative weight of a sample of soil, it is necessary to procure a field sample which has been disturbed as little as possible. Special apparatus is made for this purpose, but fairly satisfactory results can be obtained by using a baking powder tin having the top and bottom removed. This is carefully pushed or hammered into the soil till the top of the tin and the surface soil are level. Dig around the tin to give a clear space, and using a sharp spade make a horizontal cut under the tin and thus lift the tin with the soil it contains. Strike off the top soil level with the top of the tin, and weigh. The weight of soil is obtained by subtracting the weight of the tin. Make several determinations and take the average weight. Very carefully measure the tin and estimate its cubic contents in centimetres. One cubic centimetre of water weighs 1 gram. How many times heavier is the soil than water? This is its specific gravity. Having found the specific gravity of soil, calculate (1) the weight of soil moved in trenching a plot 30 ft. x 9 ft. to a depth of 18 inches. (1 cubic foot of water weighs 62½ lb.) (2) Find the weight of soil on 1 acre of ground to a depth of 9 inches.

AERATION

In a dry soil the pore space will directly influence the amount of air it is capable of holding. If, however, the soils are partially saturated with water, then the one holding the greater percentage of moisture will have its air content correspondingly reduced. The value of air in the soil is discussed elsewhere, but it is necessary here to note that proper aeration necessitates free movement of both air and water. This can only happen when the individual pore spaces are large, as in sand. Owing to clay holding such a large quantity of moisture, and to the small individual pore spaces preventing free circulation of air, the aeration of this type of soil is poor. These two reasons are probably a sufficient explanation of the apparently contradictory statement that while clay possesses a very high percentage of pore space it is very poorly aerated. It must be recognised that aeration or ventilation depends not so much upon the total air present as upon its free circulation.

Exercise 4.—To demonstrate the permeability of puddled clay and puddled sand to air:—Set up two bottles with outlets. (See Fig. 58.) With the outlets closed by screw clips on rubber tubing, fill the bottles with water. Into a filter funnel fit a small piece of filter paper followed by the puddled clay to completely cover the filter paper, and then insert the funnel into a stopper and into one of the bottles. Proceed similarly with the puddled sand. Open the two bottles simultaneously and note the effect. What do you conclude?

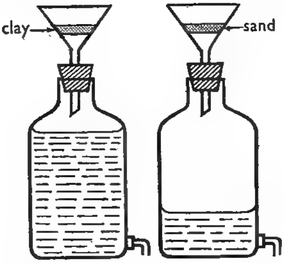


FIG. 58. Permeability of puddled clay and puddled sand to air

(*After Russell*: '*Lessons on Soil*', p. 15)

PERMEABILITY TO WATER

The speed with which water can flow through a soil will depend to a large extent upon the amount of friction to which it is subjected. Where the individual pore spaces are large as in sand the flow is rapid; on the other hand the flow is at a minimum in clay. (Fig. 59.) In some cases the clay particles appear to be so small that there is no true flow but the water moves through interstices or cracks. The permeability of soil to water is important since the possibility of effectively draining the land will depend largely on this factor.

Exercise 5.—To demonstrate the permeability of puddled clay and puddled sand to water:—Taking the two funnels used in the permeability to air experiment (Exercise 4), set them in tripods over beakers and pour a little water into each funnel. Note the effect and give your conclusion.

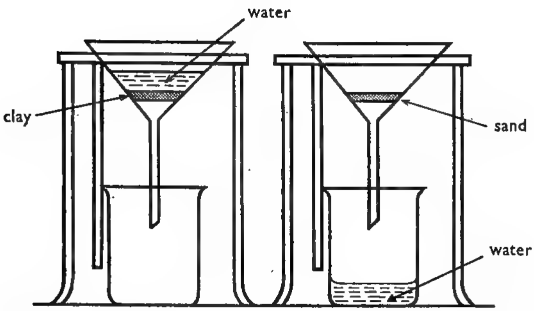


FIG. 59. Permeability of puddled clay and puddled sand to water

MOISTURE IN SOIL

Soil moisture can best be understood by relating it to three terms—permanent wilting point of plants, field capacity, and gravitational moisture. When the amount of moisture in a soil falls to a certain level plants wilt, at first temporarily and later permanently. When the moisture is at the temporary wilting stage, plants recover if watered, but at the permanent stage they do not. The *permanent wilting point* is determined by growing seedlings in well-moistened soil placed in an open glass jar. The surface of the soil, after the seeds are planted, is covered with wax and the pot kept at a constant temperature. When the leaves wilt they are placed in a bell jar with a saturated atmosphere and left overnight. If there is a recovery the wilting is only temporary and the experiment is continued until recovery is not made. The amount of moisture in the soil is then determined and expressed as a percentage of the oven-dry weight. It has been found that most plants used in agriculture wilt at about the same moisture content on the one kind of soil. The percentage varies from soil to soil mainly depending on texture. The lighter the soil the lower the figure.

Field capacity is the maximum amount of water that a soil will hold against gravity. This is determined in the laboratory by placing soil in a tin with holes in the bottom, moistening the soil well and allowing it to drain. Evaporation from the soil is prevented by placing a moist cloth over the tin. The soil is at field capacity when the moisture content is steady. The value can also be obtained in the field by irrigating with about 6 in. of water a small square of ground enclosed by a sod wall. After being allowed to drain for about a day the moisture present is the field capacity.

The following table shows the wilting point and field capacity figures for some soils from Canterbury, Waikato and Kerikeri.

Location	Texture	Wilting point per cent	Field Capacity per cent
Canterbury	Sandy-sandy silt	3.5–5.5	25
Canterbury	Silt loam	6–10	30
Canterbury	Heavy silt loam	10–13	37
Waikato	Silt loam	33	89
Kerikeri	Friable clay	20–24	55–60

The Canterbury figures are similar to those quoted for other countries and are typical for most New Zealand soils except those of volcanic origin of which the Waikato and Kerikeri figures are samples. The volcanic soils often hold more water when pastures on them are wilting than the ordinary soils do at field capacity.

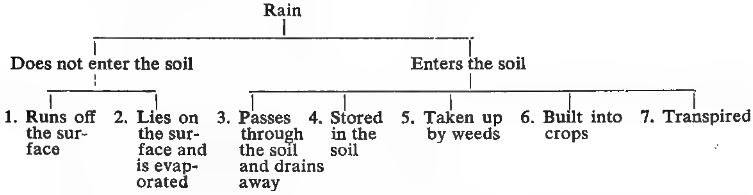
The moisture present over and above that which can be held against gravity is termed *gravitational moisture*. Such moisture is present in waterlogged soils, and in most soils during heavy rain. Given good drainage it rapidly percolates downward by gravity, and any excess is removed in the form of drainage water. If a soil remains waterlogged for any length of time, harm is done to most agricultural plants, since the air is expelled and the pore spaces filled with water.

Plants can obtain sufficient moisture if the percentage of moisture in the soil lies between permanent wilting point and field capacity. There is no optimum value between these points. Moisture is just as much available in a soil a little above the wilting point as in one in which it is nearly up to capacity.

Numerous experiments have shown that movement of water by capillarity is an important factor only when the soil is at or above field capacity. After heavy rain or after irrigation a soil may be moistened to field capacity and the removal of moisture from the top 12 in. of soil takes place by evaporation or by plant roots. When this soil is dried out there is no upward movement of moisture from the subsoil into the topsoil—the only method by which the plant can obtain the subsoil moisture is by sending roots down into it. A bare fallow is helpful in conserving moisture because the cultivating kills weeds and thus prevents loss of moisture by transpiration. (See Chapter 15.)

RAINFALL

The following table affords some suggestions as to what happens to the rain that falls:—



The rain that falls either enters the soil or does not enter. In the table the fate of the rain is accounted for in six ways, each of which is worthy of a short discussion.

1. *Does not enter and runs off the surface.*—If plants are to get any benefit from this rain it will be necessary to so alter the conditions that it *will* enter. If the surface of the soil is hard and caked the rain does not readily pass in, but flows off the surface, and may carry away with it a great deal of soil. The main cause of the trouble, however, is not the surface, but rather the subsoil, which is often very hard just immediately below the depth to which ploughing is generally carried out. If the surface soil is open it soon becomes saturated, because the water passes so slowly into the subsoil. If this is the cause either drainage or subsoiling is necessary, while if the surface soil is hard, ploughing or discing will have to be resorted to. In the case of land under pasture, mole draining may be advocated.

2. *Does not enter and lies on the surface till evaporated.*—The conditions in this case are very similar to those of the former, except that there is lacking even the natural surface drainage. Stagnant water on the surface of land will rapidly cause crops and fruit trees to die, while the evaporation of the moisture will keep the soil very cold.

3. *Enters the soil but percolates through and drains away.*—This loss is common in sandy soils possessing poor water-holding capacity. A good deal can sometimes be done in increasing the water-holding capacity of the surface soil by green manuring, and the use of farmyard manure.

4. *Stored in the Soil.*—Water that is not drained away moistens the soil aggregates and remains in them until removed by plant roots or, in the case of the topsoil, by evaporation as well.

5. *Taken up by weeds.*—Every weed can be looked upon as a pump which is lifting moisture from the soil and transpiring it into the air. During summer, when moisture is an important factor, weeds may waste a considerable amount, thereby reducing the yield of growing crops, or of a crop that is yet to be sown.

6. and 7. *Built into crops and transpired.*—As this was discussed in Chapters 4, 5 and 6, it needs no comment here.

WARMTH OF THE SOIL

This is an important factor in considering the value of land, especially for the production of early crops.

Aspect.—A northern slope or aspect in the southern hemisphere and a southern aspect in the northern hemisphere is warm and suited for the production of early crops. This is readily understood when we consider the position of the sun, which in the southern hemisphere rises in the east, and passing over the north, sets in the west. In the accompanying diagram (Fig. 60) the curve XY represents a hill. The beam of sunlight AB covers an area of the northern slope represented by CD. A similar-sized beam ab covers a much larger area cd on the southern slope, and therefore gives less heat per unit area than on the northern aspect. Proof of this point can easily be obtained by taking daily or weekly readings of the soil temperature on a northern and southern slope.

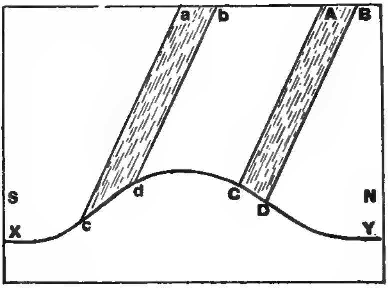


FIG. 60. Diagram showing greater warmth of northern slope in New Zealand

Exercise 6.—If a natural hill is not available, a large mound of earth can be made in the garden presenting a slope of about 30° to 45° to the four cardinal points. Care should be taken to make the mound at least 9 ft. by 9 ft. at the base, otherwise the warmth absorbed on the northern aspect will pass to the southern by conduction.

Colour of Soil.—The soil obtains most of its heat by radiation from the sun, and its power of absorption depends very largely on colour. Black soils absorb most, red soils more than yellow, while the least amount is absorbed by white or light-coloured soils. During the cool night, heat is radiated from the soil, but in this matter colour does not play any part. Thus the extra heat absorbed by a dark soil is retained. The influence of colour on temperature can be readily demonstrated in the field.

Exercise 7.—A plot of ground is selected which has had perfectly even treatment. Two areas are marked off, each of several square yards, and one top-dressed with lime, and the other with soot or bone char. Temperatures should be taken over as long a period as possible, or failing this, hourly records taken throughout a sunny day. The same fact can be demonstrated by using shallow boxes filled with soil. If the soil is dry, and the boxes are inclined towards the sun, striking results can be obtained. The boxes receive the maximum of heat, and the soil being dry there is no evaporation from the surface.

Evaporation as Affecting Temperature.—Sandy soils are usually light in colour, but it would be incorrect to suppose these cold. The question of evaporation of moisture from the surface is an important factor in determining the warmth of the soil. It takes ten times as much heat to raise a pound of water 1° of temperature as it does a pound of dry soil, and it takes more than 500 times as much heat to evaporate the water.

The canvas water-bag and porous butter cooler are familiar examples where direct use is made of the absorption of heat during evaporation.

Exercise 8.—Take the air temperature of the room. Place the thermometer bulb in a bottle of ether, and without removing it take the temperature. Now remove the thermometer, and note the movements of the column of mercury for a few minutes. The wet and dry bulb thermometers indicate the same fact regarding the heat absorbed when a liquid turns into a gas.

From these considerations it is evident that in a well-drained soil where the water never lies about the surface, but any excess is immediately carried away in the drains, we have conditions favourable for the maximum warmth of the soil.

Careful records prove that the temperature of air nine inches above the surface is warmer on drained than on undrained soil. As the loose soil of a mulch is a relatively poor conductor of heat, mulching has been found useful in lessening the rise in soil temperature under excessively hot conditions. In this connexion we must also consider the cooling effect of wind. Hedges and shelter-belts, in checking the wind, reduce evaporation and keep the soil warm.

The properties essential to an early soil are generally present in one which is coarse-textured, well-drained, crumb-structured and having a northern aspect. The afternoon sun is capable of drying the soil more thoroughly than the morning sun. For this reason a north-eastern aspect is warm and moist, and a north-western generally hot and dry. A coarse-textured soil holds very little moisture, and a great deal more heat is required to raise, to the same number of degrees, a given weight of water than the same weight of soil. It follows, therefore, that these soils must warm more rapidly than those holding a large amount of moisture.

Exercise 9.—In one beaker place 50 grams of water, and in another beaker 50 grams of air-dry soil. Take their temperatures. Into each beaker pour 50 grams of hot water at a temperature of about 30° C. above the temperature of the water in the beaker. On adding the hot water immediately stir the contents of the beakers, and take the temperatures. Now calculate (a) through how many degrees the hot water raised the soil temperature, (b) through how many degrees the hot water raised the temperature of the cold water. Draw your own conclusions regarding the amount of heat required to raise the temperature of a wet and a dry soil.

READING

Lessons on Soil, Russell, E. J.
Good Soil, (Chapter 16), Brade-Birks
Rural Education Bulletin, Sept. 1952
N.Z. Journal of Agriculture, Jan. 1954, p. 67

11

The Chemical Properties of Soil

SOIL fertility is dependent on many factors. Some of these, particularly the physical conditions such as good depth in which roots can function properly and good structure and tilth for maximum air and water supplies, have already been discussed.

Let us now consider some of the chemical attributes of a fertile soil. First, the soil must have inherited all the mineral elements essential for plant growth or have had any deficiencies made good by fertilisers or manures. Second, these elements must still be present in the upper horizons within reach of plant roots. Third, there must be sufficient of the elements near the plant root hairs to satisfy the needs of the plants growing in the soil. Fourth, there must be no excess of certain mineral elements because this may check plant growth.

All minerals taken from the soil must be absorbed by the root hairs in close partnership with the finest of the soil particles and the soil solution. The minerals capable of being absorbed are spoken of as *available minerals*. The large reserves of total minerals are in most cases rendered available too slowly for our quick-growing crops. It is therefore found necessary to resort to the application of manures which contain these minerals in a more readily available form.

When a soil chemist refers to the mineral elements present in a soil and their availability to plants, he does not mean that the elements occur as elements alone, for they usually occur as compounds of varying complexity and varying solubility. Reference to elements is merely a matter of convenience.

In soil surveys, as we saw in Chapter 8, chemical studies of the profile of a soil help considerably in deciding what a soil has inherited from its parent rock and what has happened to that inheritance by leaching and other processes. Such inheritance can often be traced in the suites of a soil and it may be determined whether the whole suite is deficient or whether there is a stage of development at which deficiencies are likely to occur. These studies also give a useful guide as to the elements which are available or which can be made available in the upper part of the soil. Soils with similar profiles belong to the same soil series and experience with one soil in a series is likely to be of value in deciding the treatment of the other soils in the same series.

Such an important decision as to how a soil should be treated chemically demands, however, still more direct evidence about the soil. This is obtained by testing the soil for available minerals. Of the 15 elements known to be essential for plant growth (see Chapter 4) 12 come from the soil. Those most commonly deficient in New Zealand soils are phosphorus, calcium, potassium, sulphur, and molybdenum. In special areas there are deficiencies of boron and copper, and also, from the viewpoint of the grazing animal only, cobalt and iodine which are absorbed by plants but apparently are not needed by them. Where continuous cropping is practised and where pastures lack vigorous clover, there is usually a shortage of nitrogen.

SOIL TESTING

Soils are tested for their chemical needs in several ways: topdressing trials on selected soil types with lime and fertilisers; pot experiments; plant analysis; and soil analysis.

Topdressing Trials

A farmer himself can get some idea of whether or not a certain paddock needs lime or a fertiliser by running a lime or a fertiliser drill strip across the paddock and comparing the growth on the strip with the growth on the rest of the paddock. Stock may graze more heavily the topdressed area than the rest of the paddock.

More accurate trials are carried out by agricultural scientists who select paddocks of a certain soil type, topdress them in strips with several replications of each treatment as a check on differences due to soil variations, and measure the growth by weighing mowings of the pasture from small representative areas protected from stock for short periods. Trials with fertilisers containing important elements have been or are about to be laid down on most of the soil types in New Zealand. The results obtained on any one soil type are very useful in considering the needs of other areas of the same soil type. Such results strictly apply only to the area on which the trial is placed, so that, in using the results, 'man-made differences superimposed on the original soil pattern' must be taken into account. Field trials provide the standard findings with which other methods, quicker but often less accurate, are compared. While reliable, such trials are slow to yield results and only limited numbers are possible.

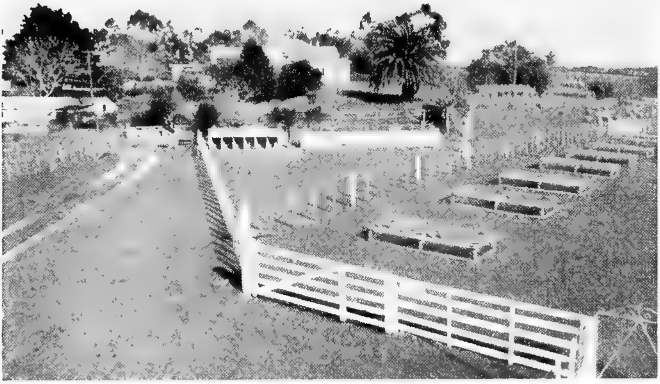


FIG. 61. Part of the Department of Agriculture's Rukuhia Soil Research Station. Note the areas protected from stock for short periods

(*N.Z. Journal of Agriculture*)

POT EXPERIMENTS

Indicator plants are grown in pots of treated soils in glasshouses under controlled conditions. Such experiments form a useful link between field trials and laboratory investigations.

PLANT ANALYSIS

Leaves from plants in a certain soil are either heated to ashes which are chemically analysed or their leaf stalks are chopped up and the extracted sap is analysed. Such analyses are compared with the usual concentrations of elements in the same kind of plants growing on fertile soil and such comparisons may reveal soil conditions in which one or more elements are in short supply. A plant analysis usually shows that shortage of an element is accompanied by an accumulation of others, e.g., a low reading for potassium often goes with high readings for phosphorus and nitrogen. Plants can grow well without such elements as cobalt and iodine which are, however, essential for animals. Plant analysis is of special importance in this connexion because it may reveal deficiencies of these elements and so point to the means of avoiding deficiency diseases of animals grazing on pasture that is otherwise vigorous.

Soil Analysis

Soil analysis is not regarded in New Zealand as being as reliable as paddock trials. There are four steps taken in a soil analysis:—Taking the soil sample, preparing the sample, shaking the sample up with a special extracting chemical and determining the amount of element extracted, and interpreting the results.

The aim in sampling a soil is to get a *representative sample,* i.e., a sample which represents the average position over a field, the usual sampling unit. About 15 cores of soil are taken with a sampling tool to a depth of 3 inches in pasture and 6 inches in ploughed land at random all over the paddock avoiding obvious small irregularities.

After drying, crushing and mixing the sample in the laboratory, a soil chemist treats a measured lot of the soil with the appropriate extractant for phosphorus or calcium or potassium and determines the amount of the element in the extracted solution by a suitable method.

Then follows the *interpreting of the soil analysis.* This means considering the result of the analysis, which is merely a set of figures, in relation to the following:—

(1) The soil profile and the type of soil analysed, e.g., clay, loam, or sand.

(2) The other physical conditions of the soil, e.g. depth, structure, and moisture supply. These may be factors limiting growth.

(3) The results of topdressing trials on paddocks with the same soil type. These are most important, providing as they do standards for comparison as already discussed.

(4) The fertilising and liming history of the paddock. Previous topdressing should be reflected in the soil test, e.g. a regularly limed paddock should be only slightly acid.

(5) The grazing, haying, draining and other management history of the paddock; e.g. a hay paddock may be low in potassium.

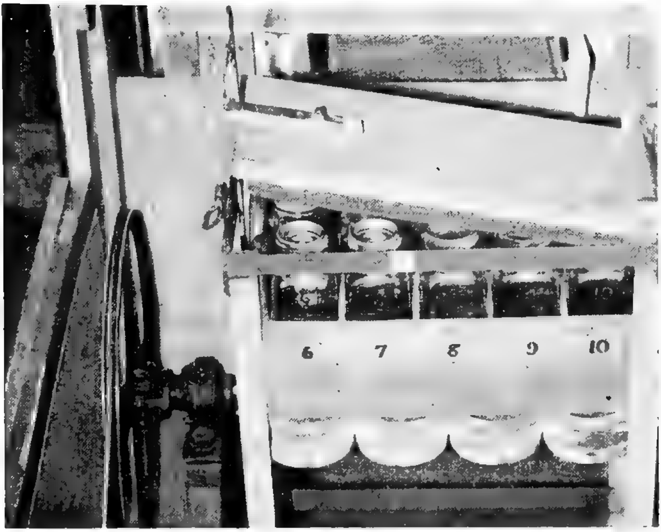
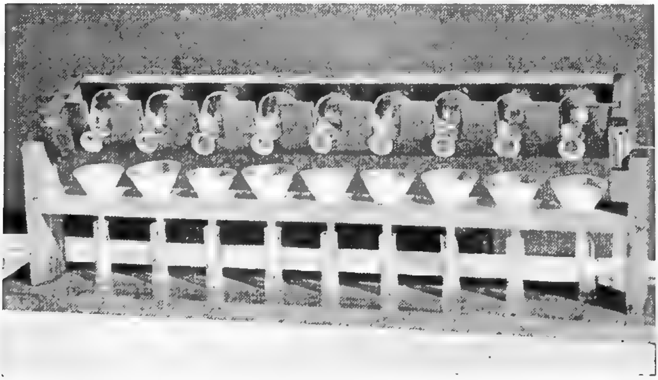


FIG. 62. *Above*: Twenty bottles containing measured volumes of soil and the acid used for extracting the phosphate are capped and shaken in the one operation. *Below*: A quick extraction method used for calcium and potassium. Nine samples are treated in one batch, but the shaking lasts only a minute

(*N.Z. Journal of Agriculture*)



(6) The nature of the growth of pasture or of crop on the paddock, especially whether or not signs of deficiency are apparent in the leaves, e.g. a white flecking of clover leaves occurs when potassium deficiency is severe.

(7) The kind of crop to be grown in the soil, e.g., cereals need less phosphorus and potassium than legumes and potatoes.

(8) Whether or not the fertiliser that appears to be required is likely to provide a profitable return.

It can be readily understood then that a soil analysis by itself is of little value, but that it can become valuable when considered along with other lines of evidence. Especially must the soil analysis figures have 'a background of soil test results from field experiments enabling one to associate levels below a certain critical value with deficiency and those above with adequacy'.

By extraction with chemical solutions, as outlined above, a soil chemist aims to reach an understanding of the amounts of minerals available to plants in that soil, and the *supplying power* of the soil for minerals. The *total amount* of essential minerals in a soil is usually very much greater than the *available amount,* the unavailable portion acting as a kind of reservoir. The total amount is no guide to the amount available and it is possible for a soil to have a high total amount of an element such as phosphorus but for plants growing in that soil to be suffering from phosphorus starvation. The soil reservoir of minerals is, however, a leaky one, for there is constant loss by leaching.

NITROGEN

The supply of nitrogen as nitrate and ammonium salts for plants is closely related to the organic matter and living organisms in soil. (See next chapter.) There is no reliable quick chemical test for the nitrate supplying power of a soil.

POTASSIUM

Field trials and soil tests show potassium to be deficient in many North Island soils. In pasture the growth of clover is a good indicator of potassium status. Where a deficiency of potassium exists, superior growth of clover in urine patches is often clearly evident, much of the potassium in the pasture being returned to the soil in the urine.

PHOSPHORUS

Most New Zealand soils are deficient in available phosphorus and are able to supply little from their mineral reservoirs in spite of, in many cases, regular applications of phosphate over many years. This is due to inheriting little from the parent rocks and to the phenomenon of *fixation* about which as yet little is known. After application phosphate is in some way turned into highly insoluble compounds by the soil organic matter, by tight absorption in the clay and by combining with iron and aluminium. There are many soil types which bring about fixation of phosphate.

CALCIUM

Deficiency of calcium, so common in New Zealand soils, is usually remedied by the liming that is carried out mainly to correct soil acidity. However, as more than half the content of superphosphate is calcium sulphate (gypsum), some soils, though fairly acid may, if regularly treated with superphosphate, contain sufficient available calcium. Special tests are used to assess soil reaction (acidity and alkalinity).

SOIL ACIDITY

Largely due to the high rainfall, to little calcium being inherited from the parent rocks, and, in some areas also, to the nature of the original vegetation such as the kauri, the great majority of New Zealand soils are highly acid. The acidity of a soil is probably the most important factor governing the availability of essential elements in that soil. Most of the minerals in a soil are held in the finer constituents, in the clay and the humus collectively called the *colloidal* part of the soil, and it is this part that gives a soil acid characteristics.

A molecule of an acid contains one or more hydrogen atoms combined in such a way that they can be exchanged for atoms of other substances. When an acid is dissolved in water, hydrogen atoms tend to separate from the acid molecules and form what are called *hydrogen ions*. The more this separation takes places the stronger is the acid. Thus, if an acid such as hydrochloric acid is dissolved in water almost all its hydrogen is in the form of ions, whereas with an acid such as acetic acid (contained in vinegar) few hydrogen ions are produced and so it is a weak acid.

Similarly the colloidal part of a soil is usually a weak acid. From the surfaces of the colloidal particles in the soil solution a small proportion of positively charged hydrogen ions (cations) are liberated into the solution leaving the colloid negatively charged. The hydrogen cations remain near the surface of the colloid due to the attraction of the negative charges on the colloid.

CATION EXCHANGE (Base Exchange)

It is this layer of cations over the surfaces of the colloidal particles that carries on a very important chemical activity in the soil called cation exchange or base exchange. Positively charged ions or cations of calcium, potassium, magnesium and sodium in the soil solution are able to change places with hydrogen ions in the outer layer of the electric double layer. This double layer consists of the negative charge on the colloidal surface in balance with the positive charges of the hydrogen, calcium, potassium, magnesium and sodium ions. The greater the amount of colloid, clay and organic matter, in the soil the greater the *cation exchange capacity*. This is one of the most important processes in nature of special concern to agriculture and therefore we shall consider it further.

If substances producing cations in the soil solution like calcium carbonate, sodium nitrate, potassium chloride, and magnesium sulphate are added to a soil, the cations calcium, sodium, potassium and magnesium are able to change places with the hydrogen in the outer colloidal layer and a new balance is set up. The colloidal balance is always such that the soil solution is a dilute solution of cations while the outer colloidal layer holds most of the cations. When fertilisers, as above, are added, not only is the soil solution enriched by cations immediately available to plants but also a reserve of available cations is built up in the soil colloids in which they are held and prevented from being lost by leaching. Further, by replacement of hydrogen ions, cation exchange reduces acidity. Conversely, as plant roots, microbes and other living organisms breathe out carbon dioxide, carbonic acid is formed producing hydrogen ions which replace other cations in the outer colloidal layer. The replaced cations, mainly calcium and magnesium, are lost by leaching and the soil solution becomes more acid. Thus the more *saturated* the colloidal outer layer is with metal cations instead of hydrogen the less acid is the soil solution. Conversely the more *unsaturated* the colloid is, that is, the more hydrogen ions, (and aluminium ions also, replace other cations,) the more acid the soil solution becomes.

THE IMPORTANCE OF SOIL ACIDITY

The soil colloids then act as reservoirs for cations of value to plants, allowing these cations to be exchanged for hydrogen and so altering the acidity of the soil solution. In regions of low rainfall and high temperatures evaporation losses often exceed rainfall (or irrigation additions). Salts are no longer leached out, but accumulate, and the soil becomes base saturated and alkaline. Special means then have to be taken to wash out the excess alkali. It is important that soil acidity be measured because a soil can become either too acid or too alkaline for the requirements of the plants to be grown in the soil.

If a soil is too acid, consequent on the loss of calcium and magnesium by leaching, a high proportion of aluminium, iron and manganese cations enter the soil solution causing harm to plants and to beneficial soil microbes. Under acid conditions, too, phosphate fertiliser is 'fixed', i.e. turned into highly insoluble compounds such as iron and aluminium phosphates which seem to be almost completely unavailable to plants. With pasture under very acid conditions, the better grasses and clovers give way to inferior pasture plants. On the other hand a soil can be made too alkaline by *over-liming* causing important cations, viz. manganese, copper, boron, zinc and iron (trace elements) and the anion, phosphorus, to become unavailable. Slight over-liming on heavy soils may do little or no harm, but on sandy and peaty soils trace element deficiencies are likely to develop. To sum up, there must be a proper balance of cations in the soil exchange system to promote healthy plant growth and this is usually achieved by proper liming and fertilising to maintain a soil pH of about 6.0 to 6.5.

MEASURING SOIL ACIDITY

In measuring the acidity of weakly acid solutions such as the soil colloids in soil solution the *pH scale* is used. This scale shows the hydrogen ion concentration in units 1 to 14. The larger the number the lower the intensity of acidity. It is a back-to-front scale like the scale measuring gauge of wire, the larger the gauge number the thinner the wire. With soils, however, not all the scale is used because soils seldom record much below pH 4 or much above pH 8. Most New Zealand soils are in the range pH 5 to 6.5. Only the very deep peats in New Zealand show pH below 4.

Table Showing Soil Reaction

pH of Soil	*Nature of Reaction*
8 or more	Alkaline
7.5	Slightly alkaline
7.0	Neutral
6.5	Very slightly acid
6.0	Slightly acid
5.5	Medium acid
5.0	Strongly acid
4.5	Very strongly acid
4 or less	Extremely acid

The best pH for pasture and most crops is about 6.0 to 6.5, i.e. just on the acid side of neutrality. Some plants grow best in fairly strongly acid soils, e.g. rhododendron, camelia and heath. An acid soil is desirable also for oats and turnips, and for potatoes, especially if potato scab disease is present. Most vegetables, particularly leeks, cabbages, beet, and lettuce succeed at or just above or below neutrality, but most flowers under slightly more acid conditions, some exceptions being carnations, lilies, and daffodils. Lucerne and barley do best in slightly alkaline or neutral soils. The organism causing club-root of brassicas develops mainly in acid soils so that liming an infected soil to neutrality or slight alkalinity reduces the incidence of the disease.

There are two main ways of measuring the acidity of a soil, an accurate electrical method and a simpler, less accurate, indicator method.

Exercise 1.—Get a representative sample of a plot of soil, push it through a sieve of one-eighth inch mesh to break up the lumps and then thoroughly mix the sample. Avoid touching the soil with your hands. Take a saltspoonful of this soil, damp but not wet, damp it if necessary, place it in a white dish and add a few drops of a soil indicator solution. A red colour indicates strong acidity, orange medium, and yellow slight acidity. Green indicates neutrality, and blue alkalinity.

The character of the vegetation is, to some extent, an indication of the lime supply of a soil. If plants, such as burnet, clovers, lucerne, sainfoin, medicks, and cranesbill do well, then probably lime is present in sufficient quantity. If sorrel, spurry, rushes, sedges and heaths prosper, then probably lime is necessary. The vegetation is, however, not a reliable guide.

LIMING

REDUCING SOIL ACIDITY

Ground limestone is the usual substance applied to soils to reduce their acidity. Most New Zealand soils require reduction in soil acidity, but soils with the same degree or intensity of acidity, pH, differ in the amounts of lime they need. A decision about how much lime an area needs, the *lime requirement* of the soil, depends chiefly on,

(1) the pH of the soil;

(2) the texture of the soil, especially the amount of clay, and the amount of organic matter present;

(3) the depth of the soil to be treated, greater in arable land than in pasture land;

(4) the kind of crop to be grown; and

(5) the kind of ground limestone to be used.

One way of describing the lime requirement of a soil is to say that it is that amount of lime needed to raise the basic cation level to 60 per cent of saturation, when calcium and the other cations essential for plant growth are in a properly balanced state. Another way is to say that it is the amount of lime needed to raise the pH of the soil to the level required by the crops to be grown in that soil. As a clay soil with a given pH contains more exchangeable cations, including hydrogen, than a sandy soil of the same pH, it will need more ground limestone to reduce its acidity. This is shown in Fig. 63 for three soils of varying cation exchange capacity but with the same initial pH. Copy this figure on to squared paper and find graphically the amounts of ground limestone required to bring each of the soils to a pH of 6.5.

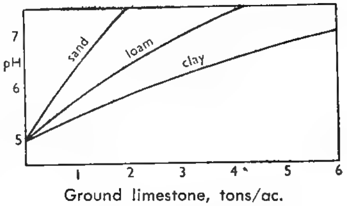


FIG. 63. Typical graphs for the neutralisation of three soils—a sand, a loam and a clay, all with initial pH of 5.0

(*After Davies, from N.Z. Dept. of Agric., Bull.* No. 240)

As with soil analysis the results of laboratory lime requirement tests must be checked with the results of field trials with lime. How the kind of limestone used affects lime requirement will be discussed in Chapter 13.

Exercise 2.—To estimate the lime requirement of a garden plot. Find the pH of a representative sample of the soil of the plot as in a previous exercise, and the texture by the Whitney method. Supposing your soil is a usual one following neutralisation curves similar to those in the figure of typical graphs for the neutralisation of a clay, a loam, and a sand, estimate the weight of ground limestone required to raise the pH of your soil to pH 6.5—e.g. If the pH of your soil is approximately 5.0 and it is a clay loam, about 3 tons of ground limestone an acre will be required, and if your plot measures 6 yd. by 10 yd. = one-eightieth acre, then one-eightieth × 3 × 2240 lb. = 84 lb. This is the weight of ground limestone that will be required.

LIMING IN RELATION TO SOIL STRUCTURE

As we saw in Chapter 10 liming tends to improve the structure of most heavy soils. While all the cations are equally effective in replacing hydrogen in acid soils and so reducing acidity, calcium is the best for promoting good soil structure. Thus, if the outer layer of the soil colloid becomes highly saturated with sodium, as when a soil has been flooded with seawater, and the salt with its flocculating action washed out, or when too heavy dressings of sodium nitrate fertiliser are made to a heavy soil, then the clay becomes sticky and impermeable. Fortunately the calcium cation is able to replace the sodium cation in the soil exchange system so that heavy application of gypsum (calcium sulphate) will restore the desirable soil structure. This has an important application in reclaiming land from the sea for agriculture.

BENEFICIAL EFFECTS OF LIMING SOIL

It is convenient now to summarise the benefits derived from liming soil discussed in this and earlier chapters and to be referred to also in the next chapter. By reducing the acidity of an acid soil almost to neutral point:—

(1) Soil reserves of essential elements, including the trace element molybdenum, are made more freely available and so the yield and quality of crops and pasture are increased. Thereby too the need for fertilisers is somewhat reduced.

(2) Out-of-season growth of pasture tends to be promoted.

(3) The fixation of phosphorus and other elements is reduced.

(4) The solubility of aluminium, manganese and iron is reduced to below the toxic level.

(5) The essential element calcium is supplied to plants, clovers and lucerne especially needing this element, and thence supplied to animals needing it mainly for bone and milk production.

(6) The structure of heavy soils is improved largely due to the flocculation of the clay colloids.

(7) The activity of earthworms is increased promoting good drainage, aeration and warmth in the soil.

(8) The breakdown of organic matter into humus, and into elements available again to plants, by soil microbes is facilitated, and the activity of nodule bacteria in clovers is promoted.

(9) The club-root disease of brassicas is checked.

NOTE:—Liming to much above pH 6 reduces the availability of all trace elements except molybdenum.

FREQUENCY OF LIMING

In New Zealand, lime seems to be lost from the top soil of well-limed soils at the rate of from 3-5 cwt. of calcium carbonate per acre per annum. It is important therefore that initial dressings should be heavy and be followed by annual dressings of the above order, or their equivalent every few years.

Lime must not be regarded as being always essential. Some soils contain adequate amounts. If it is deficient its use improves the soil in many respects, making it more suitable for crops. In other words, it facilitates the removal by plants of the soil's store of nitrogen, phosphorus, potassium and the other essential elements, which must be constantly returned if the soil is to remain fertile. Lime does not add to the soil supply of these elements, and hence cannot be looked on as a substitute for fertilisers. Again, lime is not a substitute for tillage or drainage. Indeed, liming is but one feature in the economic and rational management of soils.

Finally, when fertilisers are applied regularly, and a system of farming adopted that adds periodically to the organic matter of the soil, liming is likely to prove of the greatest value.

INCREASING SOIL ACIDITY

Under some conditions measures have to be taken to increase soil acidity. With *calcifuges* (lime-avoiding plants) such as rhododendron, and with alkaline soils (as on the sites of old

Maori pipi shell deposits) it may be necessary to add sulphur which, with sulphur-oxidising bacteria usually present in soil, produces sulphuric acid for increasing soil acidity. To get rid of earthworms and their casts on golf greens and to encourage the finer-leaved grasses like browntop and Chewings fescue it is often necessary to increase the soil acidity by topdressing with the acid-producing nitrogenous fertiliser, sulphate of ammonia.

It is convenient at this stage to consider the action of *sulphate of ammonia* in increasing soil acidity. (See also Chapter 13.) On adding sulphate of ammonia to a soil the ammonium cations replace calcium cations in the soil exchange system. The displaced calcium cations then unite with the sulphate anions from the fertiliser and the two are lost by leaching. After a time the ammonium is turned into nitrate by nitrifying bacteria (see Chapter 12) and the nitrate combines with calcium to form calcium nitrate which is either lost from the soil by leaching, or the nitrate anions are taken up by plants freeing the calcium cations to re-enter the exchange system. The tendency therefore is for calcium cations to be lost to the soil as calcium sulphate and as calcium nitrate in so far as the nitrate is not taken up by plants. After long continued application of sulphate of ammonia the loss of exchangeable calcium becomes so great, if ground limestone is not present in the soil, that the soil becomes highly acid and soluble aluminium salts present are inimical to the growth of all but acid tolerant plants.

SOIL-LESS CULTURE (Hydroponics)

As we saw in Chapter 4, plants can be grown in water containing the necessary elements without soil, and this is the basis of soil-less culture which is of value where soil is unobtainable or inconvenient to use. It has been shown that plants such as lucerne when grown in soil require a pH close to neutrality but when grown in water-culture are successful at pH round about 4. This seems to indicate that the non-success of plants in acid soils may be due to lack of calcium rather than to the acidity itself. In certain acid soils plants may succeed in spite of the acidity because exchangeable calcium is high.

RETENTION OF MINERALS BY THE SOIL

Many of the substances supplied as fertilisers are soluble in water, and it is important for us to know the fate of these substances in the event of rain falling in sufficient quantities to bring about percolation to the subsoil or to the drains.

Nitrogen, when applied as nitrates and ammoniacal salts is soluble in water. So also are the nitrates formed by the decomposition of organic matter and subsequent nitrification. All the potassium salts are soluble in water, and superphosphate, the most important of the phosphatic manures, is also water-soluble. Lime, which plays such an important part in soil fertility, is in the soil turned into the bicarbonate, in which form it is water-soluble.

The examination of drainage waters has shown the presence of large quantities of lime, either as bicarbonate, nitrate, sulphate, or chloride. Very small quantities of ammonia, potassium, and phosphorus are detected in drainage water, and we must conclude that these substances are in some way retained by the soil. We would also be correct in concluding that both lime and nitrate salts are washed into the drains and consequently lost to the soil.

The changes which take place are partly chemical, and partly physical. Clays consist of small particles and have the largest aggregate surface area so the retention is very complete, while in sand it is poor. The presence of a sufficient supply of humus and lime are also two factors which play an important part in this connexion.

In experiments carried out by Dyer, at Rothamsted, it was determined that as much as one-half of the estimated additions of potash during 50 years were still to be found in the surface 9 inches, after allowing for the amount annually removed in crops. Calculating in this way Dyer also found that no less than 83 per cent of the phosphoric acid applied during the last 50 years (less that taken out by crops), was to be found in the surface 9 inches. Robinson and Jones, on the other hand, have found that in North Wales 200 pounds of P_2O_5 applied as slag had entirely disappeared in ten years. Workers in India and Sweden have also found considerable downward movement of phosphates.

It has been found that in parts of New Zealand, e.g. Marton, there is a distinct downward movement of added phosphate but in other parts, e.g. Waikato, there is evidence that the phosphate added over a period of years is retained in the top inch of soil.

It is fairly obvious that the ability of a soil to retain added phosphates depends upon the physical and chemical properties of the soil, and also on the climate, and rainfall.

The power of soils to retain these plant minerals can be very strikingly demonstrated by passing weak solutions of the various fertilisers through columns of soil, and testing the drainings.

Exercise 3.—Set up three lamp chimneys full of friable loam, and treat as follows:—

1. Pass through a solution of superphosphate made by mixing as much of the manure as will cover a shilling, in 250 ml. of water. Test the original solution, and also the first portion percolating through the soil, by warming a few drops in a test-tube with some *ammonium molybdate* solution acidified with nitric acid. A yellow precipitate indicates phosphates. Sand might also be tried, and if any of the phosphate is not fixed, mix with the sand a little burnt lime, and repeat the experiment. The solution must not be allowed to boil because boiling will produce a yellow-white precipitate of molybdic acid even if phosphorus is absent.

2. Pass through a solution of ammonium hydroxide, of sufficient strength that the smell of ammonia is slightly perceptible, and gives a distinct *alkaline* test with *litmus* paper. After the liquid has passed, test the first portion collected, both by smell and by litmus paper.

3. Pass through a solution of ammonium sulphate made up by dissolving as much of the fertiliser as can be held on a threepenny bit, in 250 ml. of water. Test before and after with *Nessler's Solution.* A yellowish-brown coloration indicates the presence of ammonium salts. This test is extremely delicate, the least trace, as that often found in drinking water giving a decided reaction.

READING

'The Lime Requirement of Soils'
N.Z. Dept. of Agriculture Bulletin, No. 240

Rural Education Bulletins, Oct. & Dec. 1946, July 1954

Canterbury Chamber of Commerce Agriculture Bulletins,
Nos. 283, 284, 294, 312, 328

N.Z. Journal of Agriculture, Apr. & Oct. 1953, Mar. 1955

Massey Agriculture College Sheepfarming Annual,
1949 & 1954

Soils and Manures in New Zealand, (Chapters 3 & 6)
Wild, L. J.

Soil Conditions and Plant Growth, (Chapter 7)
Russell, E. J.

The New Farming, (Chapter 2)
Robinson, D. H.

12

The Biological Properties of Soil

SOIL MICROBIOLOGY

THE importance of organic matter and humus in soils has already been stressed. Humus greatly improves the structure of soil and its water-holding capacity; it plays a prominent part, along with clay, as colloidal material concerned in cation exchange. Organisms living in organic matter promote the weathering of soil minerals; they affect soil development; they are concerned, as we shall see in this chapter, with important transformations of nitrogen and other necessary elements which nourish both microbes and plants and therefore ultimately all animal life. So important indeed is the organic matter with its living organisms that *soil microbiology* has become a major branch of soil science and the supply of organic matter in a soil is often the determining factor in the fertility of the soil. From soil are prepared many *antibiotics* of importance in medicine.

In a soil there is a complex system of microbes and other forms of life, chiefly bacteria and fungi but also protozoa and algae, all competing with one another for food and all affecting one another's development and chemical activities. As in the rest of nature, a balance tends to be established between these competing organisms, a balance, however, which is ever changing as the physical and chemical conditions of the soil change.

The most valuable microbes in soil are *bacteria* which are extremely minute plants, so small that they have to be magnified from 500 to 1000 times under a microscope before they can be seen. There may be several thousand millions of bacteria in a saltspoonful of soil. Bacteria are very minute and simple plants but differ from ordinary plants in not being green, and therefore being unable to assimilate their food substances in the same manner as the green plant. Their minute size is compensated for by their rapid multiplication. This is frequently effected by splitting into halves, and each half growing and again splitting into half. When we consider that under favourable conditions they may split every half-hour, we can see that even one bacterium will multiply into an enormous number in 24 hours. If conditions of water and food supplies become unfavourable, the protoplasm of a bacterium contracts and a coat is formed preventing loss of moisture and creating resistance to heat and chemicals. This resistant body is called a *spore*.

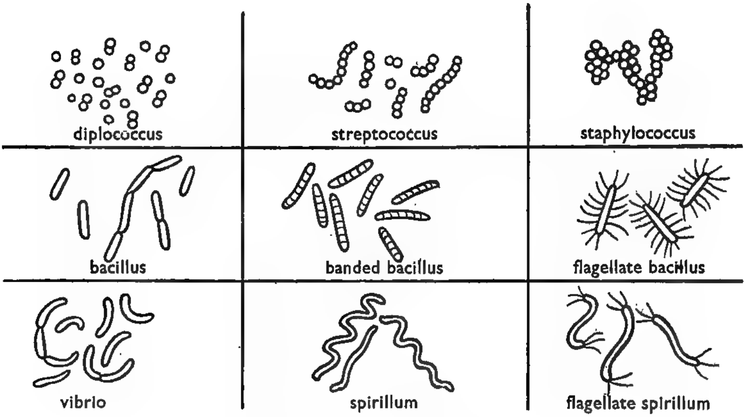


FIG. 64. Types of bacteria

DECOMPOSITION OF ORGANIC MATTER

The process which we term decay, both in animal and vegetable matter, is brought about by *putrefactive bacteria*. These are of two kinds, those which live in the presence of air—*aerobic organisms*, and those in the absence of air—*anaerobic organisms*. The former attacking organic matter bring about *oxidation* changes, eventually resolving the substances into simple compounds, water, ammonia, nitrogen, and carbon dioxide. The ammonia and nitrogen eventually form plant foods, and the carbon dioxide assists in many other changes already referred to. On the other hand the anaerobic organisms turn the organic matter black in colour, a process called *humification* which results in the formation of a material called humus. At this stage no further changes take place until suitable conditions are brought about for the aerobic organisms to complete the decay.

In a soil both these changes take place. In so far as a soil is well aerated the organic matter decays, liberating its plant food substances for the use of the crops. When and where a soil is less well aerated humification occurs. Under well-drained arable conditions aeration is at a maximum and the organic matter in decomposing not only yields nitrogen compounds useful to crops, but also is dissipated into carbon dioxide and water. At the other extreme with a badly drained swampy soil anaerobic conditions are maintained and the organic matter accumulates and forms what is generally termed peat.

Generally speaking, bacteria do not thrive in an acid medium, and the rate of decay is very much retarded when the neutral point is passed. By the application of lime any acid present is neutralised, and the decay takes place more rapidly. This explains the common reference to lime 'burning out' the organic matter in the soil. Not only is lime, judiciously applied, beneficial in this connexion, but it increases the activity of many other bacteria which bring about valuable changes in the soil.

NITRIFICATION

With the liberation of ammonium compounds resulting from the decomposition of organic matter, a series of changes occurs described as *nitrification*. They are brought about by *nitrifying bacteria*, and consist of oxidising the ammonium compounds liberated from the decay of organic matter into *nitrates*. These are the only forms in which plants, except the legumes, are capable of taking nitrogen to any extent, and the importance of the change, therefore, cannot be too strongly emphasised. Upon it will depend the supply of nitrogen to the crops, and under many circumstances the amount of growth is proportionate to the amount of nitrogen available.

The nitrifying bacteria make use of the ammonium ions as they are held in the soil cation exchange system so that the greater the amount of colloid (clay and humus) present the greater the amount of nitrification.

Exercise 1.—Demonstration of nitrification in soil. To a sterilised tube of 1 per cent peptone solution add a small piece of soil. After intervals of a few hours:—test some of the solution for the presence of ammonium compounds, (Nessler's solution goes yellowish-brown); test for nitrates, (ferrous sulphate solution goes dark brown); test for nitrate, (diphenylamine solution goes blue). Repeat the tests until positive results are obtained.

The presence of any acid in the soil will check nitrification, and since nitric acid is the final product of the change, it follows that the application of lime, to form a base with which the nitric acid can combine, is of primary importance.

Since nitrification is an oxidation change, large supplies of oxygen are essential. Drainage and tillage both play a very important part in this connexion.

Bacteria in general require a certain amount of warmth, the optimum temperature for nitrifying bacteria being about 98° F. During the winter the soil temperature is frequently below this, nitrates are but sparingly produced, and growth is slow. The yellow, unhealthy appearance of crops during a wet and cold winter or spring can generally be attributed to the lack of nitrates. Crops—especially garden crops—are considerably benefited by the application of a little nitrate of soda during the spring, and the use of this fertiliser as a topdressing for wheat during early spring is the general practice in England. On the other hand in Australia the winter is not so cold. The soils do not experience the heavy rain which leaches out any nitrates formed, and which prevents the formation of fresh supplies by cutting off the air supply. Consequently in the spring there are nitrates in sufficient quantity for the wheat crop, and the application of more nitrogen would only cause rank growth, which is by no means desired.

Finally, to sum up, increased nitrification is brought about by:—

1. Thorough aeration of the soil—tillage and drainage.
2. Maintaining a sufficiently high temperature—drainage.
3. A base to neutralise the acids as they are produced—liming.
4. Darkness, and a sufficient supply of moisture and plant food.

DENITRIFICATION

This term refers to changes taking place in the soil whereby the nitrates are destroyed. This change, carried on by denitrifying organisms, is directly detrimental, and results in the loss of a most important plant food. Bacteria capable of denitrification are everywhere abundant. In actual farming, loss from this cause is only likely to be pronounced when nitrogenous manures, especially nitrates, are applied on sour and wet land, or are applied together with heavy dressings of farmyard manure or other organic matter.

FIXATION OF FREE NITROGEN BY BACTERIA

Bacteria have been isolated which are capable of bringing into combination in the soil the *free nitrogen of the atmosphere*. Some work independently, requiring only a supply of organic matter which they oxidise. These free bacteria, notably azotobacter, are essentially aerobic, and the organic matter supplies them with the necessary energy for the fixation of the free nitrogen. In pasture which is running wild, and in which the organic matter produced is again returned to the soil, these organisms bring about a gradual increase of available nitrogen. To these bacteria must be attributed much of the richness of virgin land. They are probably not very active in cultivated land, since the organic matter they require is considerably reduced. They cease activity in an acid soil, hence the necessity of maintaining the supply of lime.

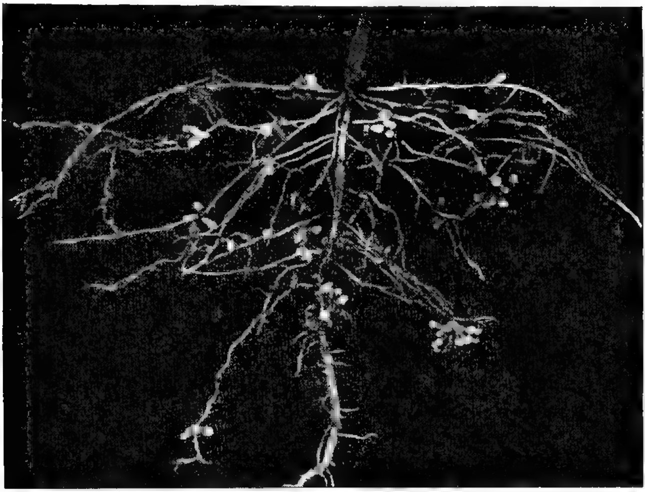


FIG. 65. Bacterial nodules on the roots of french bean

BACTERIA LIVING IN SYMBIOSIS WITH LEGUMES

There is another and very important process whereby the soil's nitrogen content may be increased by drawing on the large store of atmospheric nitrogen. The bacteria involved in this connexion are not free, but act in conjunction with the leguminous or pod-bearing family of plants, of which clovers, lucerne, lupins, peas, beans, lotus, sainfoin, trefoil, serradella, and vetches, are all important members. Some leguminous plants do not have nodules. If a healthy member of a nodulating legume is carefully dug up, and the soil washed away, an examination of its roots will reveal small wart-like structures termed *bacterial nodules*. (Fig. 65.) These nodules are in reality colonies or groups of a definite class of bacteria. The organism is a rhizobium and, as is explained below, there are a number of different strains. Since these bacteria are living in partnership with the host, this co-operation for mutual benefit is termed *symbiosis*. The organisms, in common with all other bacteria, are not green, and are unable to manufacture their own carbonaceous matter from the air. They are in fact entirely dependent on the host plant for their supply of carbohydrates. In return they make available to the plant nitrogen which they are able to fix from the free nitrogen of the air present in the soil. The most vital food for leguminous plants is nitrogen, and yet in actual practice it is rarely necessary to apply any specific nitrogenous manure on account of the activities of these bacteria. Further than this, a leguminous crop, even when harvested and carted off the land, leaves the soil richer in nitrogen in contrast to any other class of crop which invariably leaves the soil poorer. These bacteria obtain their carbohydrates from the plant, and they are consequently independent of the supplies present in the soil. Provided there is, in the soil, a sufficient supply of essential plant elements other than nitrogen, especially calcium, phosphorus, and molybdenum, and good air and water supplies, and correct pH, these bacteria will work readily in soils extremely poor in humus, and likely therefore to be poor in nitrogen.

Some soils are poor in the specific bacteria required for the crop that is grown. It becomes necessary, therefore, to inoculate the soil, that is, to add the required bacteria, usually as a coating on the seed. The best results are obtained when each species is directly inoculated from nodules taken from the same kind of plant. In dealing with the cultivation of lucerne this matter is further discussed. Suffice it to say here that although it was only in 1886 that the researches of Hellreigal and Wilfarth cleared up the problem, soil inoculation had been practised for many years past. In parts of France it was the custom for one farmer to 'bless' his neighbour's field in which lucerne was about to be sown. The blessing took the form of sprinkling over the field some soil from his own lucerne patch.

That a leguminous crop has the correct strain of root-nodule bacteria may be determined by the growth which should be of a dark-green colour and the nodules should be large, situated on or near the tap roots, and pink on the inside.

EARTHWORMS

Of all the macroscopic organisms (i.e. organisms that can be seen with unaided eyes) in soil, earthworms are the most valuable. As already noted, earthworms improve soil structure and promote good aeration and drainage in soils.

In New Zealand pastures one kind of earthworm, the *casting earthworm* called *Allolobophora caliginosa,* has important beneficial effects on pasture growth. Several years after its advent into root-bound danthonia-browntop pasture in the King Country, the growth of ryegrass and clover was markedly stimulated. This improvement cannot be assigned solely to the improvement in the physical properties of the soil. Secretions of the earthworms, perhaps hormones contained in the discharges from the 'kidneys', may be a major factor in the improvement.

The food of earthworms is organic matter of any kind except certain types, notably pine needles. Most earthworms must also have a continuous supply of calcium as they do not live in very acid soils or soils without calcium. One earthworm common in good pastures in New Zealand is called the *manure earthworm, Lumbricus rubellus,* named thus because it feeds largely on dung, so distributing this and rendering it more available to plants. The presence of this earthworm in abundance in a pasture is an indication of high fertility. In the case of a pasture on very fertile soil 'the weight of the earthworms living *in* the soil is approximately equal to the weight of the sheep living on the herbage *above* the surface'.

Exercise 2.—To compare the earthworm populations of two kinds of pasture. Select two small plots in a pasture, the one of high quality and the other of low quality. Water each plot with a dilute solution of potassium permanganate at the rate of one gallon to seven square feet. When the worms are forced to the surface by the irritating effect of the solution on their skins, count and weigh them. Compare the counts and weights and sizes of the earthworms in the two plots.

Just as the supply of organic matter in an arable soil is often the limiting factor to the fertility of that soil so is the supply of available nitrogen often the limiting factor to fertility in many soils. A summary of the circulation of nitrogen is given in Fig. 66.

INFLUENCE OF PASTURES

Because repeated cultivation of a soil usually results in the loss of organic matter, in spite of ploughing in crop residues, it is usually necessary, in arable farming and gardening, to replenish the supply of soil organic matter. In New Zealand the most economical way of doing this on a farming scale is to grow pasture containing clover for several years. The time a soil can be cropped before its organic matter supplies diminish to too low a level depends to a large extent upon the texture of the soil, for the

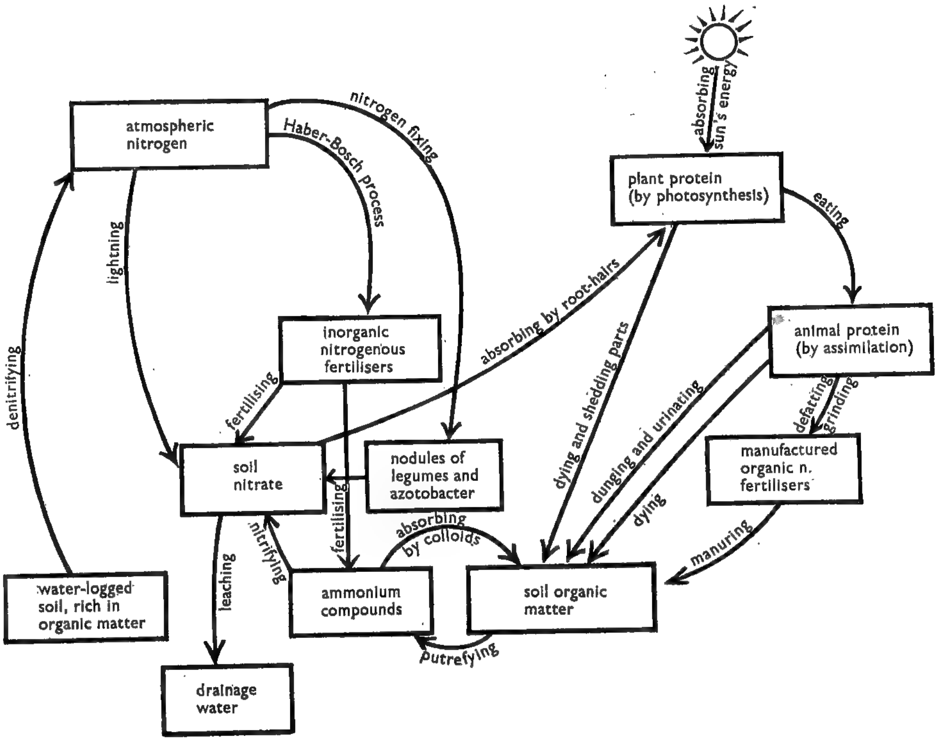


FIG. 66. The nitrogen cycle

lighter the soil the quicker the loss of organic matter and the shorter the time that the soil can be cropped. Replenishment of the organic matter in soils growing pasture which is grazed results from the dung distributed by harrowing and by earthworms and from the continual dying of plant roots.

On unploughable pastoral country the organic matter and nitrogen supplies are built up through stimulation of pasture growth by oversowing with clovers and by topdressing with phosphate and lime. Means to combat loss of organic matter by erosion must also be taken and burning off avoided as much as possible.

GREEN MANURING

Green manuring consists in the growing of a crop for the special purpose of ploughing it down to increase the supply of organic matter in the soil, and thereby to obtain the train of benefits already discussed. For satisfactory results the crops grown must be vigorous and of rapid growth. Mustard, barley, oats, Italian ryegrass, vetches, and crimson clover, are crops suitable for this purpose in normal circumstances. Lupins (preferably blue), at the rate of 1½ to 2½ bushels per acre have proved satisfactory on almost pure sands. *Lotus angustissimus* may be used with confidence on the gum clay country of New Zealand—*Lotus uliginosus* being substituted, however, if the situation is moist. In warm climates cow peas are used extensively for this purpose.

Green manuring, as described, is rarely practised on New Zealand farms except in extreme cases. In orchards and market gardens it is practised with profit, but for a mixed farmer it is considered more profitable to pass the crop through stock. From 50 to 90 per cent of the manurial value of the crop will in this manner be returned to the land. In many cases the last growth of such crops as rape and barley could profitably be ploughed in instead of being fed off. The question therefore, of maintaining the supply of organic matter resolves itself into the adoption of a suitable rotation wherein fodder crops play an important part.

A crop of weeds, provided they are not allowed to flower, and are not of a 'twitchy' habit, may often be put to good use in this way. On the other hand, docks, sorrel, couch, Indian doobj grass, any other twitches, and yarrow, are typical weeds totally unsuitable, and any attempt to so utilise them would result only in a worse growth of the weed. Care should be taken not to allow a green manuring crop to stand so long that the supply of moisture for the succeeding crop is impaired. A green manuring crop draws heavily on the soil water content, and thus the succeeding crop may have insufficient moisture. Again, the vegetable matter to be ploughed in should not be allowed to become woody; as a general rule it should be turned down at the flowering stage and further, it should be completely buried preferably in a chopped up condition. Discing before ploughing under a green crop achieves this. It is well, if possible, to have such matter buried sufficiently early in the season to allow decomposition to occur before the sowing of the next crop. The chief reason for this is that the decay organisms compete with plants for the available nitrogen in a soil so that while the major part of the decaying process is going on, the crop tends to suffer from a shortage of nitrogen.

FARMYARD MANURE

Much more might be done, even under our farming conditions, in preserving in an economical manner the manure that accumulates around stables and bails. Such manure should be collected at frequent intervals, and, if not applied at once to the land, stored away beneath a waterproof roof. If left in the open the rain will rapidly leach much of the valuable nitrogen and potash, resulting in material of very poor quality.

Urine is rich in nitrogen and potassium and dung in phosphorus and calcium. On dairy farms, where the milking shed is on elevated ground, the shed and yard cleanings can be collected in a tank, fed into a distributor with the help of gravity and spread over the pastures.

The Compost Heap is an important adjunct to the market garden. All kinds of rubbish can be placed on the heap to undergo decay except twitchy weeds, weeds that have been allowed to seed, and plants diseased in any way. The compost heap can become a prime factor in spreading diseases and weeds if proper attention is not paid to this matter. The heap should be made of convenient size, and allowed to decay while a second heap is forming. In building the heap, the layers of plant refuse about 6 in. deep should alternate with an activator such as sulphate of ammonia, farmyard manure or potassium permanganate. The more stemmy the material the more activator and the tighter the packing required. Each layer needs also a sprinkling of ground limestone to keep conditions sweet. As air is needed for best results, a tile drain at the bottom of the heap will be helpful. Keep the heap covered in very wet weather and water it in dry weather. It is then turned over two or three times, allowing an interval of several weeks between each turning. Spray with D.D.T. to keep away flies. When completed the material should form a friable mould.

COMPOST SOIL FOR RAISING SEEDLINGS AND FOR POTTING

In order that seedlings and pot plants may be grown with the greatest success it is necessary to have soil free from spores of harmful fungi and bacteria and free from living weed seeds. It should be well aerated, able to hold moisture and the essential minerals should be available. Compost soil is an artificial mixture designed to have these attributes. The following is a modification of the *John Innes system* of preparing compost soil:—

(1) Select a loam soil that has been several years in pasture and so of good structure. Having got a representative sample of this soil test it for pH and for texture and estimate its lime requirement. (See Chapter 11.) Either cut and stack and lime the turves of this soil six months before it is required, or cut off the pasture growth, pass the soil through a three-eighths inch mesh sieve, and lime and store the soil under shelter 3 or 4 weeks before it is required, mixing twice at intervals.

(2) Sterilise the sieved soil with methyl bromide gas passed under a plastic sheet which covers the soil in tent fashion, the edges of the sheet being held down with soil. One pound of gas is required per 100 sq. ft. of soil 6 in. deep.

(3) Prepare peat by rubbing it through a three-eighths inch mesh sieve and then making it thoroughly wet but not dripping wet. Prepare fine road metal or scoria by passing it through a one-eighths inch mesh sieve on to a one-sixteenth inch mesh sieve and use the grit in the proportion of two-thirds of that passing the one-eighths inch sieve and retained on the one-sixteenth inch sieve to one-third of that passing through the one-sixteenth inch sieve,

(4) In a concrete mixer or on a mixing board mix the prepared loam, peat and metal grit in the following proportions by volume:—

(a) *For seed boxes*: 2 parts loam, 1 part peat, and 1 part grit. Also superphosphate 1½ oz. plus ground limestone ¾ oz. per bushel of the soil mixture.

(b) *For pots*: 7 parts loam, 3 parts peat, 2 parts grit. Also superphosphate 1½ oz. plus ground limestone ¾ oz. plus dried blood 1½ oz., plus sulphate of potash ¾ oz. per bushel of the soil mixture. (1 bushel = 8 gals.)

READING

Canterbury Chamber of Commerce Agric. Bulletin, No. 171

Rural Education Bulletins, Nov. 1952, p. 146, July 1954, p. 82

N.Z. Journal of Agriculture, Apr. 1953, p. 374, June 1957, p. 552

Massey College Sheepfarming Annual, 1949, p. 114

Seed and Potting Composts, Lawrence & Newell

Science News, No. 5, Nov. 1947, p. 71

A Student's Book on Soils and Manures, (Chapter 3), Russel, E. J.

13

Fertilisers and Lime

THAT growing plants need chemical elements was first scientifically investigated by a French agriculturist, Boussingault, early in the 19th century. For example, by carefully devised experiments he showed the relative amounts of the elements taken by plants from the air and the soil. Farmers in the 19th century, too, found by trial and error that some chemical substances applied to soil improved the growth of crops. In 1840 Liebig, a German chemist, showed that the mineral requirements of plants could be supplied by simple chemical salts. Then Lawes and Gilbert at Rothamsted in England in 1843 started their field experiments similar to those of Boussingault. These experiments have become famous not only for their valuable results over the years but also because 'they are still going on, having been continued year after year on the same ground without alteration, except in occasional details, since 1852'. Lawes, at Rothamsted, also established the first artificial fertiliser works and made the first superphosphate. Progressive farmers now recognise that there are but few conditions under which the use of fertilisers does not pay. Only on some of our hilly, pastoral country, and certain particularly rich areas of alluvial soil, is the application of fertiliser either unprofitable or unnecessary.

WHY FERTILISERS ARE NECESSARY

As discussed in Chapter 11, the total supply of minerals in soil has little relation to the minerals available to plants. Thus a soil can have high total amounts of say phosphorus and potassium, but plants growing in the soil can suffer from lack of one or both of these minerals. Fertilisers then are required to supply minerals in a form readily available to plants.

In studying the formation of soil we found that the stock of minerals in a soil depends upon what it has inherited from the parent rock, the amount of leaching that it has suffered and the kind of natural plant cover it has possessed. A natural balance has developed between climate, vegetation and soil; a certain level of fertility has been established. When the virgin soil is used for farming, the balance is disturbed and the level of fertility may tend to fall. This tendency is most marked with arable farming where crops such as wheat are consumed away from the farms and where the cultivation accelerates organic decomposition and leaching. It is less marked where crops are consumed on the farms and stock foods are brought on to the farms. In efficient pastoral farming there is, in contrast, a build-up of fertility in spite of mineral losses in the livestock products such as milk, meat and wool, consumed away from the farms, provided these mineral losses, chiefly phosphorus, calcium and potassium, are made good by the use of fertilisers. Carbon, the chief element in organisms is continually being built up from the atmosphere and nitrogen also, especially with good pasture containing clover. Some of the minerals are circulating from the soil to the pasture and crops to the livestock and by way of livestock manure back to the soil. The chief aims of a good farmer in this connexion are to ensure that in the circulation there is an even distribution of minerals over his farm, that the inevitable losses are kept to a minimum and that the losses are restored economically by the use of fertilisers.

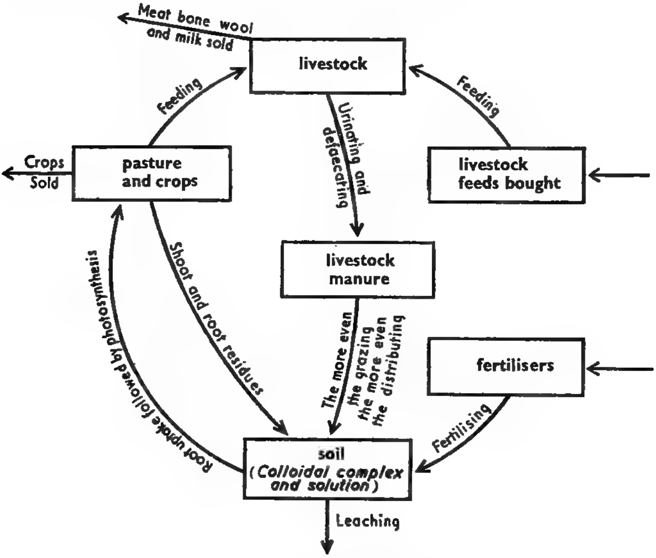

Meat bone wool and milk sold
livestock
Feeding
Feeding
Crops Sold
pasture and crops
Urinating and defaecating
livestock feeds bought
livestock manure
Shoot and root residues
Root uptake followed by photosynthesis
The more even the grazing the more even the distributing
fertilisers
Fertilising
soil (Colloidal complex and solution)
Leaching

FIG. 67. Diagram of the general movement of minerals to and from a farm. (Arrows outwards mean minerals lost from the farm; arrows inwards mean minerals gained by the farm)

CLASSES OF FERTILISERS

All farm crops require access to fifteen principal elements (*oxygen, hydrogen, nitrogen, carbon, phosphorus, potassium, calcium, sulphur, magnesium, iron, manganese, boron, copper, zinc* and *molybdenum*).

No crop can grow unless every one of these fifteen elements is present, and no crop can give a full yield unless each and every one of these elements is present up to the requirements of the crop. The last five are called 'trace' elements because they are used in very small amounts.

Although every one of the fifteen elements is necessary, yet we do not require to supply them all as fertilisers, because several occur in abundance in the soil or in the atmosphere.

As a general rule, only three elements are apt to be deficient in supply. These are nitrogen, phosphorus, and potassium, and hence we get three main classes of fertilisers—*nitrogenous, phosphatic,* and *potassic*—any fertiliser falling under one or other of these classes according to which substance it supplies to the soil. In some cases, calcium is also deficient in soil and is supplied by liming. Lime is applied also to amend the soil.

In some cases fertilisers contain quantities of each of the three substances, nitrogen, phosphoric acid, and potash. To such fertilisers the term 'Complete' is added—most of the special crop manures may be classified as *'Complete Fertilisers'*, although those sold in New Zealand are often very low in nitrogen and potash.

Again, cases occur in which the one material contains two of the three important substances: for example:—blood and bone fertiliser contains phosphate and nitrogen, and so may be correctly classified as a nitrogenous manure, and also as a phosphatic manure.

PHOSPHATIC FERTILISERS

The fertilising effect of bones has been known for a very long time, but only within comparatively recent times has attention been directed to the phosphate which they contain in large quantities, and which is their most valuable constituent. Phosphates occur in other places besides bones, and in several different chemical forms. However, since most of the phosphatic manures of importance are *phosphates of calcium,* it is necessary to discuss briefly these compounds. Synthetic ammonium phosphates are being manufactured, but the natural calcium phosphates are used in the preparation of the synthetic ones.

The typical phosphate, regarded as the starting point for manures, is *tricalcium phosphate*. It exists in bones, in guanos, and in rock phosphate which occurs in many parts of the world.

Tricalcium phosphate is neither acid nor alkaline, and is very slowly soluble in soil moisture, and totally insoluble in water. To convert tricalcium phosphate into a soluble form it is treated with acid—usually sulphuric acid—the result being *monocalcium phosphate,* such as occurs in *superphosphate*. Monocalcium phosphate is soluble in water, and hence immediate in its effect on plant growth.

A third form of phosphate which results from interaction between superphosphate and lime is known as *reverted phosphate,* its chemical name being *dicalcium phosphate*. This form, though insoluble in water, is readily acted on by the soil moisture, which renders it available for plants. Under the action of the soil moisture it becomes comparatively quick in its effects. The manure known as *basic superphosphate* is made by suitably mixing superphosphate and quicklime or slaked lime, the result, provided moisture is present, being the conversion of the monocalcic phosphate of the superphosphate into dicalcic or reverted phosphate. A somewhat similar reversion occurs when *serpentine superphosphate* is made.

A fourth form of phosphate is found in *basic slag,* which is a by-product of steel making. The phosphate is in complex form and is insoluble in water, but readily responds to the solvent action of soil moisture. From the chemical standpoint there are, then, four classes of phosphatic manures:—

1. Tri-calcic—Bone manures and rock phosphate.

2. Di-calcic—Basic superphosphate, and serpentine superphosphate.

3. Mono-calcic—Superphosphate.

4. Complex calcium phosphate—Occurring in basic slag.

FUNCTIONS OF PHOSPHORUS

1. It greatly stimulates root formation, and consequently hastens plant growth, particularly in the early stages. This stimulation in the early stage is important in connexion with crops of the turnip family, e.g. swedes, rape, and kale, because the plants grow quickly past the stage when they are apt to

suffer most from the grass grub beetle. The stimulation of root formation is of service to crops which have to be sown in a dry, warm part of the year, as in such cases the success of the crop greatly depends on getting the roots quickly down to the moister layers of soil. In a similar manner, crops such as turnips and barley, which are naturally shallow-rooting, respond to and benefit by phosphatic dressings. The increased yield of wheat effected by the application of such small quantities as 1 cwt. or less of superphosphate per acre, is largely explained by the increased root development produced in the young seedlings.

2. Phosphorus is an essential element, the adequate supply of which greatly increases not only the yield but also the feeding value of all crops and pastures.

Often the sense of taste of the grazing animals quickly enables them to discriminate between pastures which have been top-dressed with phosphates and ones which have not been so top-dressed. This is commonly observed where a portion of the pasture has been phosphated and a portion untreated, and the animals show a marked preference for the phosphated portion. The preference may be due to a more succulent herbage which is an accompaniment of the more rapid growth usually associated with the use of added phosphates.

In addition to increasing the phosphorus content of the herbage, phosphatic dressings may also increase its calcium and protein contents. Phosphorus is essential for the development of flesh and particularly of bone, as is evident from the large quantity of calcium phosphate which is present in bones.

In the case of young stock particularly, food containing adequate phosphorus is essential to allow of the formation of the bone necessary to provide a suitable body framework.

3. Phosphates have a most beneficial effect on clovers and other leguminous plants such as lucerne. This is because the activity of the nitrogen-fixing bacteria depends on an adequate supply of phosphorus for the host plant. After a phosphatic dressing, white clover may predominate in a pasture paddock in which it was not previously noticeable except by close observation. This stimulating effect on legumes enables phosphates to be used as an indirect means of improving the nitrogen content of many of the poorer soils.

4. Phosphorus is in some way connected with grain formation and it is always found in greater proportions in the seeds than in

other parts of the plants. Where phosphates remedy a deficiency their application hastens maturity. Almost all New Zealand soils have inherited little phosphorus from the parent rocks.

ROCK PHOSPHATE

Rock phosphates contain tri-calcic phosphate as do bones, but they differ from bones in that there is little or no readily-decomposable organic matter present. The tricalcium phosphate is insoluble in water, and but slowly acted upon by soil moisture. Rock phosphates vary in their rapidity of action. Certain North African and Egyptian phosphates are derived from soft phosphatic deposits, and are more quickly effective than the Nauru Island phosphates, from which most of the New Zealand superphosphate is manufactured. Provided bones are finely ground and steamed, the decay of the organic portion considerably hastens the rate at which the phosphoric acid becomes available for crops, so that bones may sometimes be quicker in action than rock phosphates when used under similar conditions.

FIG. 68. Rock-loading equipment at Nauru Island
(Dept. of Agriculture)

Rock phosphate is used as the raw material for the manufacture of superphosphate. As we in New Zealand have no high-grade deposits of rock phosphate, we are fortunate in having them lying fairly close, chiefly in Nauru Island and Ocean Island. Both these islands are situated in mid-Pacific Ocean near the equator. They furnish rock containing 80 per cent or more of tricalcium phosphate, and provide some of the highest grade material in the world for the manufacture of superphosphate. Island phosphates are sometimes referred to as guanos, e.g., Makatea guano, Seychelles guano, and in this connexion it is of practical importance to remember that the appropriation of the term 'guano' to these substances is justifiable only in respect to origin, for they exhibit only to a limited extent the characters through which the guano class of manures gained their reputation. Guanos consist almost exclusively of the excreta of sea-birds, which congregate during the breeding season in enormous numbers. They are rich in nitrogen as well as phosphorus. True guanos are rarely if ever available in New Zealand now.

SUPERPHOSPHATE

Though the existence of a soluble phosphate of lime has long been known to chemists, its use as a fertiliser began as late as 1840, the material being put on the market as superphosphate. Superphosphate of modern manufacture is a cream or grey friable powder of variable composition. Lines at present on the market usually contain from 20.2 per cent to 21 per cent of soluble phosphate, expressed as so-called phosphoric acid, or 44 per cent to 46 per cent expressed as tricalcium phosphate, which means that water soluble phosphoric acid, P_2O_5, and total phosphoric acid, both expressed as tricalcium phosphate $Ca_3(PO_4)_2$, are 44 per cent and 46 per cent respectively in the superphosphate. The phosphoric acid content may be expressed as tricalcium phosphate content by multiplying by 2.18. It should be noted that the phosphate never occurs as phosphoric acid. It is merely a conventional standard method of describing the amount of phosphate that would be present if in the form of phosphoric acid (P_2O_5).

MAKING SUPERPHOSPHATE

Any material such as bones or rock phosphate which contains a high proportion of tricalcium phosphate, 60 per cent or over, is suitable for the manufacture of superphosphate. The material containing the tricalcium phosphate is first ground to a powder, then mixed with sulphuric acid. The acid dissolves the insoluble tricalcium phosphate, forming monocalcium phosphate, and *calcium sulphate* or *gypsum*. The mixing of the acid and tricalcium phosphate results in a hot, damp mass, which is subsequently dried and pulverised.

When the impurity in the original tricalcic phosphate is limestone, the result is a comparatively large amount of gypsum, a desirable ingredient, as it causes a drier and more friable powder, and so improves the mechanical condition of the fertiliser. The gypsum (calcium sulphate) is valuable too because it contains the essential element *sulphur* which is deficient over large areas of the South Island and in some parts of the North Island. The mixture of monocalcium phosphate and gypsum, together with the impurities in the original rock phosphate, forms the commercial superphosphate.

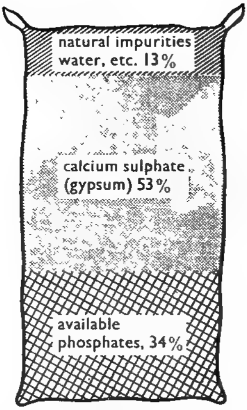


FIG. 69. Diagram to show the contents of a bag of superphosphate (*Modified from J. A. Bruce*)

In order that superphosphate may be evenly distributed from the air it is specially granulated in a granulating machine.

Although the monocalcium phosphate in superphosphate is soluble in water, it is not readily washed from the soil. When superphosphate is applied, the soluble phosphate it contains is rapidly changed to a form insoluble in water. To some extent the change is due to chemical action with minerals contained in the clay, but in most soils the calcium takes the chief part in the reaction with the production of the reverted phosphate in the manner already indicated. As the formation of this reverted phosphate takes place throughout the soil, the phosphate is thoroughly disseminated—a desirable result which is more thorough and efficient than could possibly be obtained by any process of grinding or mechanical mixing. This thorough distribution, coupled with ready solubility, makes the phosphate readily available to crops.

SERPENTINE SUPERPHOSPHATE

During World War II our supplies of phosphate were much reduced and in an endeavour to conserve them as much as possible serpentine superphosphate was manufactured. Serpentine is a comparatively soft rock composed of a magnesium silicate. A similar mineral finely ground and added to superphosphate had been found to increase the effectiveness of the phosphate in other parts of the world. The idea of using serpentine for this purpose in New Zealand originated with the late Mr. G. H.

Holford and a fertiliser made by mixing three parts of freshly made superphosphate with one part by weight of finely ground serpentine was tried as a pasture topdressing and as a fertiliser for a variety of crops. The magnesium of the serpentine along with some calcium which is also present cause the superphosphate to 'revert' to di-magnesium phosphate and di- and tri-calcium phosphate. Because most of the soluble monocalcic phosphate of the superphosphate is converted into forms not soluble in water, the fertiliser is a safe one to sow in contact with small seeds such as turnips, swedes and rape.

As a fertiliser for the topdressing of pasture it has given better results in a few cases than superphosphate presumably because of some effect from the magnesium. The general conclusion from trials is that it is at least equal in effect to superphosphate. Since it contains only three-quarters the amount of phosphate present in an equal weight of superphosphate, its use conserved phosphate during the war years.

Other advantages serpentine superphosphate has over ordinary or 'straight' superphosphate are:—it is not so subject to fixation, it does not set hard, it is freer running, it does not weaken jute bags, and it contains appreciable amounts of the element magnesium and small amounts of essential trace elements, such as manganese, zinc and cobalt.

BASIC SUPERPHOSPHATE (or Reverted Phosphate)

Another manufactured phosphatic manure is basic superphosphate or 'reverted' phosphate which was introduced in 1901 by John Hughes. It is made by mixing ordinary superphosphate with sufficient quicklime to convert the soluble phosphate into dicalcium or reverted phosphate, leaving in addition a small proportion of free lime. Since, in practice, the amount and kind of lime used often varies according to the works at which the fertiliser is manufactured, the degree of reversion also varies. The material is very finely ground, and forms a light, bulky, whitish powder, which is readily distributed. The lines at present on the market vary a good deal in the proportion of fertilising material present, ranging up to about 19 per cent of phosphoric acid. They are, however, not all true basic superphosphate. The phosphoric acid of true basic superphosphate is chemically identical with that which results when superphosphate reverts. It goes into solution with the weak soil acids fairly quickly, and this, and the fine state of division of the manure, render it fairly readily available to the plant. It may be considered as perhaps more readily available than the phosphate of basic slag. It is useful for turnips and other crops with small seeds, as, providing it is properly reverted, it is not so likely to injure germination under dry conditions as does superphosphate when sown at too great a quantity in direct contact with the seed.

TRIPLE SUPERPHOSPHATE

Also called double superphosphate, (40 per cent to 50 per cent P_2O_5) is almost pure monocalcium phosphate and is, therefore, a much more concentrated phosphatic fertiliser than superphosphate. It is made by the interaction of orthophosphoric acid and tricalcium phosphate. Trials show that when it is applied at equivalent rates of phosphorus it is about equal to superphosphate. Its lower calcium content and almost complete lack of sulphur probably make it less useful than superphosphate on many soils.

Other concentrated phosphatic fertilisers are:—

(a) *Calcium metaphosphate* (64 per cent P_2O_5) made by passing phosphorus pentoxide over heated ground rock phosphate. When mixed with twice its weight of ground limestone, it is called 'Metaphos', (21 per cent P_2O_5).

(b) *Calcium magnesium phosphate* or 'Thermophos' or 'Calmag' (20 per cent to 30 per cent P_2O_5) made by roasting ground serpentine or dunite rock with ground rock phosphate.

In a few trials in New Zealand these fertilisers, compared with superphosphate, appear to give, at equivalent rates of application, about equal responses.

BASIC SLAG

Basic slag is a dense black powder so finely ground that four-fifths of it should pass through a wire sieve carrying 100 meshes to the linear inch. It is a by-product of the *Thomas-Gilchrist* process of making mild steel—hence it was sometimes called *Thomas's phosphate*. The process, which was introduced in 1879, involves heating the pig-iron to a high temperature in a pear-shaped vessel, lined with limestone or dolomite, the object being to remove various impurities, including phosphorus, which combines with the lime and forms slag which floats on the molten metal. The slag is removed at suitable times, cooled, and pulverised.

Basic Slag is essentially a mixture of *phosphates and silicates of calcium, magnesium, iron and manganese*. From the farmers' standpoint, the main constituents are the phosphate and free lime, both of which vary a good deal. The amount of free quicklime is comparatively small—generally 2 to 3 per cent. The presence of calcium oxide, silicates, and other compounds results in 1 cwt. of basic slag having about the same lime value as 1 cwt. of a high grade ground limestone. The slag does not contain the usual tricalcium phosphate, but has its phosphorus in a complex form, the chemical nature of which is held to be responsible for the behaviour in the soil, and the ready availability of the fertilising ingredient of the slag. Its phosphate is found to be readily dissolved by a solution of carbon dioxide or any other very weak acid and a much larger proportion of phosphorus goes into solution than would be the case of rock phosphate containing the same amount of phosphorus and as finely ground. A specially valuable feature of basic slag may be its content of magnesium and of the trace elements, molybdenum, manganese, vanadium and titanium.

ACTION OF PHOSPHATIC FERTILISERS

In considering the action of various phosphatic fertilisers in the field, the soil and climate are the most important factors to be taken into account, for the relative value of the fertilisers will change entirely with different types of soil and climate. For example, the choice between superphosphate and basic slag will depend largely on the wetness or dryness of the soil or climate where the fertiliser is to be employed. On very acid soils too, basic slag may be preferable to superphosphate. The type of crop to be stimulated also deserves consideration, but it is not so great a factor as the soil and climate.

The prejudicial effect of the temporary local acidity of superphosphate on the germination of seed may be avoided by mixing it with an equal quantity of ground limestone. It should be mixed some days before use and turned over several times to avoid setting.

It must not be thought that the use of basic slag obviates the necessity for liming. On soils deficient in lime both superphosphate and slag give better results following or accompanied by liming. On the other hand slag may give better results than superphosphate if the soil is very acid. Rock phosphates, such as Nauru, and North African phosphates, often give a greater response on land that has not been limed. This is probably explained by the acid soil bringing the rock phosphate into solution more readily than one in which the acidity has been corrected by liming.

THE USE OF PHOSPHATIC FERTILISERS IN NEW ZEALAND

About half the phosphatic fertiliser used in New Zealand is ordinary superphosphate. Serpentine superphosphate, basic superphosphate, potassic superphosphate, cobaltised superphosphate and other mixtures of superphosphate with boron, copper and molybdenum and with insecticides, such as D.D.T., make up the rest of the predominantly phosphatic fertilisers. 'Super and super derivatives account for more than 80 per cent of the total fertilisers used in New Zealand.'

SOLUBILITY OF PHOSPHATES

Exercise 1.—Obtain one-half gram samples of the various phosphatic fertilisers. (a) Make water solutions of each in test-tubes, and filter. Rinse out the filter, and use a clean filter paper for each fertiliser. Take a small quantity of each filtrate in a test-tube, add excess of ammonium molybdate, and warm. A canary-yellow precipitate indicates phosphates soluble in water. (b) Repeat the above experiment, using instead of water a 2 per cent solution of ammonium citrate as a solvent. (c) Again test the solubility of the various phosphates, using on this occasion dilute nitric acid as a solvent.

REVERSION OF SUPERPHOSPHATE

Exercise 2.—Test a little superphosphate for solubility in water. Mix a small quantity of the same fertiliser with burnt lime. Grind them well together, introduce a small quantity into a test-tube, add water, shake up well, and allow to settle. When clear filter, and test as in Ex. 1. If basic superphosphate has not been tested for citrate solubility, test a little of it.

NITROGENOUS FERTILISERS AND MANURES

Since New Zealand farming is predominantly pastoral, the use of nitrogen as a fertiliser is limited. In pasture containing clover of good strain, inoculated with the appropriate symbiotic bacteria and supplied with sufficient available phosphorus, calcium, molybdenum and other essential elements, the nitrogen is passed underground from the clovers to the grasses and overground to the grasses from the urine and dung of grazing livestock. Nitrogenous fertilisers take their minor place in New Zealand for stimulating out-of-season pasture growth, particularly on town-supply dairy farms, for grass seed and cereal production and for market and home gardening.

FUNCTIONS OF NITROGEN

To lay the basis for the intelligent use of nitrogenous manures, it is necessary to consider what specific effect the excess or the deficiency of nitrogen in the soil has on the appearance and development of the crop. Though we are still far from full knowledge of the physiological functions of nitrogen in the nutrition of plants, yet laboratory and field experiments and farm experiences have definitely shown that:—

(1) Nitrogen is mainly concerned with the vegetative growth of the plant, with the formation of root, leaf, and stem, which are the necessary starting points in the process of complete development: a deficiency of nitrogen results in a stunted general growth.

(2) A markedly deficient supply of nitrogen causes a falling-off in the weight of the individual grains of cereals.

(3) An excess of nitrogen causes the proportion of grain to fall off somewhat. This will have been noticed by most farmers in the case of cereals growing on the site of old stack-butts or manure heaps, where the excess of nitrogen, due to decomposition of the vegetable matter, causes a rank growth with unsatisfactory grain formation.

(4) Nitrogen starvation leads to a yellowing of the leaves and a starved appearance generally: abundance of nitrogen leads to a dark green colour, to a copious growth of soft sappy tissue liable to insect and fungoid pests due, apparently, to the thinning of cell walls and some change in the composition of the sap. Rusts on cereals, leaf spot on mangels, and Irish blight on potatoes are all prone to be more prevalent if there is excess of nitrogen.

(5) Under moist conditions an abundance of nitrogen retards ripening, and consequently makes the harvest late which, in cases such as the oat and wheat crops, may be calamitous.

FORMS OF NITROGEN

One of the most important questions to be settled in connexion with nitrogenous manures is their relative availability and rapidity of action. Nitrogen, in addition to occurring in a free state in the atmosphere, is found in forms of importance in agriculture as:—

(a) Nitrates, which are the normal nitrogenous food of plants, although some plants can take up nitrogen in the form of ammonium salts and as complex organic substances.

(b) Ammonia and its compounds.

(c) Organic nitrogen.

The ideal nitrogen supply is one in which there is a continuous and equable amount available right through the growing period of the crop. This condition is unobtainable where the fertiliser used contains only one of the three forms of nitrogen. Nitrates alone give a quick, concentrated, but brief stimulation, which, however, may suffice for the crop's needs until the nitrifying organisms become active enough to supply the needs of the crops. Fertilisers containing ammonia provide a more continuous supply, but the most satisfactory results are obtained when the mixture contains quantities of nitrates, ammonia, and readily available organic nitrogen.

NECESSITY FOR ECONOMY

Under normal commercial conditions, nitrogen is the most expensive fertilising material that is required. For this reason much attention has been given in recent time to systems of farming which reduce, or possibly eliminate, outlay on nitrogenous fertilisers. To minimise the amount of nitrogen which has to be purchased, the following practices are advisable:—

(1) The return of arable land to pasture containing clover after only one or two years of cropping.

(2) The periodical cultivation of the nitrogen-collecting leguminous crops.

(3) The proper, economical saving and judicious application of farmyard manure which contains about 12 lb. nitrogen, 6 lb. phosphoric acid and 12 lb. of potash per ton.

(4) The growing of green manuring crops especially legumes.

(5) The feeding-off of crops *in situ*.

THE MAIN NITROGENOUS FERTILISERS AND MANURES

(1) *Nitrate of soda*.—This fertiliser contains 16 per cent of nitrogen. It is an expensive manure of quick, concentrated, and brief activity, and is valuable in wet conditions to ensure an early start in growth. It is particularly useful for leafy, bulky

crops such as cabbage, rape, broccoli, mangels. As it is easily washed away, it is preferably applied in several small dressings rather than in one large dressing. In New Zealand its agricultural use is restricted. It may be usefully employed to stimulate a backward crop. In practice it is used mainly in market and kitchen gardens. It has been shown to be effective on cereals in the South Island of New Zealand, but at present prices its use is likely to be profitable only for use on intensive market garden crops. Its repeated use on heavy soils tends to destroy tilth. This can be corrected by using a mixture of about two parts of nitrate of soda to one of sulphate of ammonia; the mixture to be applied immediately it is made.

Nitrate of soda has an indirect fertilising effect which is particularly valuable. It acts on potash compounds in the soil, and brings the potash into solution, thus making it available for crops. To such an extent does this action take place that a dressing of nitrate of soda on any but potash-deficient soils tends to dispense with the necessity of specific potash manuring, even for potash-loving crops. Mangels are recognised as potash-lovers, and Hall, of Rothamsted, publishes results showing that the use of nitrate of soda has enabled the soil to supply the mangel crop with the potash it needs for twenty-five years.

(2) *Sulphate of ammonia,* containing 20.6 to 21 per cent of nitrogen, is, next to the nitrates, the quickest-acting nitrogenous fertiliser. Synthetic sulphate of ammonia is now the most common form of nitrogenous fertiliser, the nitrogen being extracted from the air, mainly by the Haber-Bosch process.

Under normal soil conditions sulphate of ammonia is changed into nitrates in the soil, but this does not take long in ordinary circumstances, and unless quick action is especially desired there is little to choose between sulphate of ammonia and nitrate of soda. The two fertilisers contrast in respect to the following points:—

(a) Sulphate of ammonia tends to cause most soils to become acid; hence it tends to increase sorrel and repress clovers and other legumes. This may be avoided by adequate liming. Usually about 1½ cwt. of carbonate of lime, i.e. good ground limestone, is required to correct the acidifying effect of 1 cwt. of sulphate of ammonia. Some soils are able to resist acidification, and their acidity is not materially affected by sulphate of ammonia.

(b) Sulphate of ammonia tends to correct harm done to the tilth of the soil by use of nitrate of soda.

(c) Sulphate of ammonia, being less easily removed from the soil than nitrate of soda, should be preferred on open, porous soils, and in districts of high rainfall.

(3) *Nitrolim* or *calcium cyanamide* is a nitrogenous fertiliser containing about 20 per cent nitrogen and about 20 per cent free lime. In general properties it is much the same as sulphate of ammonia, and British tests have shown that it is almost, but not quite as effective. If kept for a long time or mixed with superphosphate a chemical change takes place resulting in the formation of a substance toxic to plants. Calcium cyanamide should be applied beneath the surface a week or two before a crop is sown, and not used in contact with seeds or for top-dressing purposes.

(4) *Nitrochalk* is a synthetic product containing about 15.5 per cent of nitrogen. It is a mixture of ammonium nitrate and finely divided calcium carbonate, and has the disadvantage of absorbing moisture readily. Its granular form is in a very fine mechanical condition and it should be used immediately after opening the special waterproof bags in which it is contained. Because it contains a nitrate its action is very rapid.

(5) A very concentrated synthetic nitrogenous fertiliser is *Urea* (46 per cent N.). It is often the main constituent of those garden fertilisers designed to stimulate leaf growth of vegetables. If added to a soil without liming high soil acidity may result.

(6) *Dried Blood*.—This by-product from abattoirs has become very popular but is difficult to procure. The percentage of nitrogen is usually 12 per cent to 13 per cent. It is used extensively by manufacturers for mixing with bone-dust and other fertilisers in the production of 'complete' manures. It should not be sown in close contact with seed. Apart from this it is essentially a safe manure, little inclined to 'force' crops, and is quite a suitable nitrogenous manure for open, porous and sandy soils. On soils of this type it is quick in action, being readily decomposed.

In addition to dried blood, other by-products from abattoirs are prepared and sold under various names. The common abattoir manures consist of dried flesh, offal, and bone-dust. They are excellent manures, but slower acting than soluble fertilisers. An advantage they have over the synthetic nitrogenous fertilisers is their trace element content.

PHOSPHATIC-NITROGENOUS FERTILISERS

These may be divided into (a) Inorganic, (b) Organic.

(a) INORGANIC

The fixation of atmospheric nitrogen has opened up enormous possibilities for the exploitation of the use of nitrogenous-phosphatic fertilisers. Considerable development on a commercial scale in Germany, United States of America, and Great Britain has taken place in the manufacture of ammonium phosphates. The chief products are (1) Monoammonium phosphate, commercial samples of which contain 10 per cent to 11 per cent of nitrogen and 48 per cent to 52 per cent of phosphoric acid. (2) Diammonium phosphate, containing 20 per cent to 21 per cent nitrogen and 52 per cent to 53 per cent of phosphoric acid.

These ammonium phosphates are mixed in various proportions with one another and with sulphate of ammonia to give a variety of nitrogenous-phosphatic fertilisers. For instance, a fertiliser under the name of Ammo-phos is sold in two grades, viz.:—

Ammo-phos, 10.7/48 (10.7 per cent N. and 48 per cent P_2O_5).

Ammo-phos, 16.5/20 (16.5 per cent N. and 20 per cent P_2O_5).

A mixture of equal parts gives a fertiliser containing 13.6 per cent N. and 34 per cent P_2O_5.

'Complete' fertilisers containing nitrogen, phosphorus and potassium are made by mixing ammonium phosphate with potassic fertilisers, such as muriate and sulphate of potash, and are sold under various trade names, such as 'Nitrophoska', and 'En-Pe-Kay'. Although these fertilisers vary in composition they are nearly all highly concentrated, and most of the constituents are soluble in water. It seems highly probable that they will play an important part in the future. The fact that they are so concentrated reduces the cost of cartage and handling. For example, 100 lb. of diammonium phosphate may contain as much phosphate and nitrogen as 350 lb. of a mixture made up of sulphate of ammonia and superphosphate. On the other hand, high concentration may not be altogether advantageous unless highly efficient distributing machines are used, on account of the difficulty of obtaining a uniform distribution of such a small quantity per acre. Such material as gypsum, in superphosphate, has its advantages. In trials these concentrated fertilisers have been tested against an equivalent amount of P_2O_5, K_2O and N in a less concentrated mixture made up of superphosphate, sulphate of potash, and sulphate of ammonia. Sometimes they have been equal, sometimes the lower concentrated mixture has been better, but in no case has the concentrated mixture been recorded as superior.

In the newer concentrated fertilisers the phosphate is always expressed as P_2O_5, whereas in New Zealand the phosphate in say superphosphate, would be expressed as tricalcium phosphate in commercial advertising. Diammonphos, with 52 per cent of P_2O_5 would be shown to contain 113 per cent if expressed as its tricalcium phosphate equivalent.

(b) ORGANIC

The more common phosphatic-nitrogenous fertilisers are organic, such as bonedust and blood and bone, which are by-products from freezing works and boiling-down works.

Blood and bone is a common by-product from the meat industry. It consists of all the waste parts of carcases from which the fat has been extracted. It varies in composition but contains as a rule from 6 to 7 per cent of nitrogen and from 11 to 12 per cent of P_2O_5.

Steamed bonedust contains from 3 per cent to 4½ per cent of insoluble nitrogen, and from 20 per cent to 28 per cent of insoluble phosphoric acid.

It is derived from crushing the residue from bones from which the fat or greasy matter has been largely removed. This removal of the fat leaves the gelatinous matter which contains the nitrogen, and the mineral framework which contains the phosphoric acid in the form of tricalcic phosphate. The process of crushing rarely results in a really fine powder, because the gelatinous matter (cartilage) interferes with the disintegration unless special methods are employed. The nitrogen present can be looked on as being rather slowly available. Bonedust is, in general, rather slow-acting as a source of phosphoric acid when compared with superphosphate and basic superphosphate. Steamed bonedust contains 1.5 to 3 per cent of nitrogen and from 22 to 27 per cent phosphoric acid.

Green bonedust is slower in its action than steamed bonedust, owing to the presence of a certain amount of grease, which retards the chemical action of soil moisture and soil bacteria.

Bone fertilisers have been used in one form and another for a very long time. They may be looked on as safe dressings, that is, they will give fair returns under different conditions of soil, climate, and crops. Because of these facts they enjoy a good reputation, and sell at a price which is found to be excessive when proper consideration is given to their chemical analysis and to the efficiency of their components.

Exercise 3.—The following exercises enable us to detect the presence of nitrogen, whether as organic, ammoniacal, or nitrate-nitrogen:—Obtain samples of dried blood, sulphate of ammonia, and nitrate of soda. Treat each fertiliser in the following manner:—

(a) Mix separately in a mortar about as much of the fertiliser as can be heaped on a shilling, with four times its weight of soda-lime. Place the mixture in an ignition tube and heat. In the case of sulphate of ammonia there is a strong smell of ammonia without even heating. On heating, the dried blood gives off ammonia, which can be detected by smell or by its ability to turn a moist piece of red litmus paper blue, and moist turmeric paper brown.

(b) Place a little of each fertiliser in a test-tube, half fill with sodium hydroxide or potassium hydroxide, and boil. Ammonia will be given off from the sulphate of ammonia only.

(c) Take small samples of each of the fertilisers in test-tubes, add water, shake up and filter. To the clean filtrate add a few drops of indigo solution; then pour in very carefully strong sulphuric acid till the volume is about doubled. With nitrate of soda the indigo will be bleached.

Summary:—

1. Nitrate nitrogen indicated by indigo test.
2. Nitrogen in ammonia compounds is distinguished from nitrogen in organic matter by the fact that the former gives off ammonia when treated both by caustic potash and soda-lime, while the organic gives off ammonia only when treated with soda-lime.

POTASSIC FERTILISERS

OCCURRENCE OF POTASSIUM

Potassium is distributed in the rocks which form the crust of the earth in considerable quantities, and as it occurs in compounds which are not easily washed out, the soils derived from these rocks usually contain considerable quantities. Clays and loams usually contain considerable stores of potassium in a form not readily available, but it is important to remember that some soils such as those composed largely of quartz sand, and sometimes deep peaty soils, resulting from the drainage of swamps, show a poverty of potassium. In these latter cases, the only remedy is to supply potassium. A large proportion of New Zealand soils contain potassium which becomes available in sufficient quantities for most of the main crops. Again, some districts are markedly deficient in potash, and give excellent response to the application of potassic fertilisers. Where the parent rocks of New Zealand soils were not rich in potassium-bearing minerals and where the rainfall is high resulting in much weathering of the minerals and leaching of the potassium, the soils contain little or no reserves of potassium. This applies to many soils in the North Island and some in the South Island. Hence, after several years of grazing on such soils, potassium deficiencies tend to arise and more and more farmers have to apply potassic fertiliser as well as phosphate. Potassic fertilisers are all easily soluble in water but in soil they enter and are held in the colloidal complex and so are not easily lost in the drainage except in sandy soils.

The term 'potash' is often used in speaking of potassic fertilisers. It is rather a loose term for we speak of:—

(a) *Carbonate of potash,* which is the chief potassium compound occurring in *wood ashes* after they have been exposed to the air; or

(b) *Oxide of potassium,* which is the substance referred to when we speak of the percentage of potash in manures. The term potash should be used to signify only oxide of potassium (K_2O).

FUNCTIONS OF POTASSIUM

(1) Although potassium is not a constituent of protoplasm, it seems to be essential in photosynthesis in the building up of both carbohydrates and proteins.

(2) Increasing the supplies of available phosphate and nitrogen in a soil frequently shows up an inadequate supply of potassium. Starvation for potassium is commonly indicated by premature death of leaves.

(3) The tone and vigour of the plant are very dependent on the potassium supply: potassium-starved crops are the first to suffer in a bad season, or to succumb to disease. Rusts on cereals and grass, leaf spot on mangels, blight on potatoes, and other fungoid troubles have all been noted to be more prevalent in potassium-starved crops than on those well supplied with potassium.

(4) The clovers and other leguminous plants such as lucerne, are potassium lovers and respond markedly to the application of potassic fertilisers to soils deficient in potassium.

THE SOURCES OF POTASSIC FERTILISERS

The great commercial source of potassic fertilisers is the Stassfürt and Alsace-Lorraine deposits, and they are also recovered from the waters of the Dead Sea.

Sometimes from 5 per cent to 10 per cent of potassium carbonate is to be obtained from wood ashes, the greatest amounts occurring in young growth. Potash from seaweed has also been used for manurial purposes.

In Stassfürt and Alsace-Lorraine many crude salts are mined, and either sold in their impure form, or purified, and in this form largely exported.

Sulphate of potash is commonly used in New Zealand. It contains from 48 per cent to 50 per cent of potash, and forms an important ingredient in complete manures. It is completely soluble in water, and immediately available. *Muriate of potash,* containing about 60 per cent of potash is the most common of the potassic fertilisers now available. It is very expensive. Both soluble nitrogenous and potassic fertilisers are very injurious to germination, particularly if in contact with small seeds, and even when sown in a very small quantity per acre.

Wood ashes contain a varying small amount of potassium. The ashes should be sheltered from rain, which quickly washes out the soluble potassium carbonate. The characteristic prolific growth which usually results where vegetation has been burnt does not necessarily indicate potassium effect. The ash includes a large amount of lime, 10 per cent to 40 per cent, and some phosphates, 1 per cent to 3 per cent, which may produce the result observed. Partial sterilisation of the soil may also play a part. Some wood ashes have almost no potassium, e.g. Radiata pine ash contains only 0.1 per cent potash.

Farmyard manure and crop residues should all be ploughed under, as they not only contain considerable amounts of valuable potassium, but also lead to other valuable effects.

POTASSIC FERTILISER SUBSTITUTES

The store of unavailable or slowly available potassium which is present in many soils may be brought into service by the use of soil 'amendments', so called because they change the chemical relationships of certain plant foods, and bring them from the unavailable to the available form. *Salt* and *lime* are substances which may be utilised for this purpose. Field experiments to test the efficacy of salt on the mangel crop indicate a decided benefit under specific conditions, particularly when the dressings are fairly heavy. Besides being a true fertiliser nitrate of soda also acts as a soil amendment, setting free some of the store of soil potassium.

The use of soil amendments or indirect potash fertilisers, such as salt and lime, can be successful only on soil containing a store of potassium. It will probably prove effective on clays and loams, but thin, sandy soils may require the potassium supplied by using ashes, potassic fertilisers, and farmyard manure.

SULPHUR FERTILISERS

The necessity for fertilisers containing sulphur in New Zealand arises from the following situations:—

(1) That sulphides, the form in which sulphur usually occurs in soil minerals, are readily oxidised during weathering to sulphates which, being water soluble, are lost by leaching, unless taken up by plants. Thus the older a soil is the more it tends to be deficient in sulphur.

(2) That most soils contain in their humus sufficient sulphur which, when broken down by bacterial action to sulphate, becomes available to plants. However, with humus soils under low rainfall, the bacterial action may be insufficient to make the sulphur available.

(3) That superphosphate, while it supplies both sulphur and phosphorus (every hundredweight containing 11 lb. of sulphur and 10 lb. of phosphorus), provides less sulphur and more phosphorus than some soils need. This applies to those few soils in New Zealand, notably the rendzina ('tarry') soils of North Otago, the parent rocks of which were rich in phosphorus and which do not lose phosphorus by leaching. It applies also to some soils in areas of low rainfall and probably to some soils throughout New Zealand which have been heavily phosphated over many years.

(4) That there may be a future shortage of sulphuric acid for making superphosphate necessitating the use of sulphur-free

substitutes such as metaphos and thermophos. Fertilisers containing sulphur would then be required where deficiencies are evident.

(5) That, in places remote from the sea and from volcanic and industrial activity, supplies of sulphur from the atmosphere, to supplement the soil supplies, may be insufficient for the needs of plants, especially legumes.

Deficiencies of sulphur have been shown to occur chiefly in the South Island, in North Otago and in the foothills and uplands of Canterbury.

The Functions of Sulphur

(1) Sulphur is an essential element in proteins so that plants with sulphur deficiency are unable to turn nitrate into protein during photosynthesis.

(2) Legumes especially need sulphur for the symbiotic bacteria to fix soil atmospheric nitrogen, so deficiency of sulphur results also in deficiency of nitrogen.

(3) Certain plant oils such as the mustard oil from brassicas require sulphur for their formation.

Deficiency symptoms in plants are unnatural colours, yellowing and stunting.

Fertilisers Supplying Sulphur

Gypsum (Calcium sulphate) containing 19 per cent of sulphur is readily available when applied to soil. It is useful mainly in the few places where the soils are naturally rich in phosphorus.

Sulphur, the element, either as flowers of sulphur or as finely ground sulphur, is slower-acting than gypsum. It is less useful on acid soils unless it is mixed with an equal weight of ground limestone.

Superphosphate contains about 10 per cent of sulphur, and 9 per cent of phosphorus. It is fortunate from the viewpoint of satisfying plant needs for sulphur, that superphosphate has been the main fertiliser used in New Zealand. Otherwise deficiencies of sulphur in many soils would probably have been more serious.

Sulphate of Ammonia not only supplies nitrogen but also sulphur, for it contains about 24 per cent of sulphur and 21 per cent of nitrogen. Where a nitrogenous fertiliser as well as a sulphur fertiliser is warranted, then sulphate of ammonia may be a profitable source of sulphur.

TRACE ELEMENT FERTILISERS

The amounts of those elements known as trace elements necessary for healthy growth are very minute, e.g., soils containing less than 3 parts per million of total cobalt are deficient in this element, whereas others with about 10 parts per million have in general an adequate amount. As only very small quantities ranging from a few ounces to a few pounds to the acre are needed to overcome soil deficiencies, it would be difficult to apply them evenly if they were applied alone. So in New Zealand while most soils need large quantities of phosphate, it is usual to mix the compounds containing the trace elements with superphosphate. Thus we have *cobaltised superphosphate* (0.2 per cent cobalt sulphate), *molybdenised superphosphate* (0.05 per cent to 0.10 per cent sodium molybdate or ammonium molybdate), *copperised superphosphate* (1.5 per cent copper sulphate), and *borated superphosphate* (2.5 per cent borax). 'It is not unknown for a farmer to order cobaltised, copperised, molybdenised, serpentine superphosphate.' A very grave warning must, however, be sounded with regard to the use of trace element fertilisers, namely, that trace elements are all very poisonous if available in soil in excess of requirements. If, for example, molybdenum were applied to a soil already containing adequate amounts of molybdenum then grazing animals on that soil would very likely be seriously affected.

Another way of applying trace elements evenly is to spray them in dilute solutions on to the leaves of the plants needing them. This method is especially useful in orchards and gardens.

TRACE ELEMENTS IN RELATION TO SOIL ACIDITY

In an acid soil likely to have a trace element in short supply, liming may accentuate the deficiency. As a general rule, increasing the acidity of soils increases the availability of all the trace elements except molybdenum. This may go so far that very acid soils contain toxic amounts of trace elements, e.g., manganese.

A proper balance of elements is essential for the proper growth of plants and animals, and this principle applies prominently to the trace elements. If, for example, there is too much molybdenum, a deficiency of copper may be induced.

TRACKING DOWN TRACE ELEMENT DEFICIENCIES

It is difficult to decide where and to what degree trace element deficiencies exist. Soil scientists have been very helpful to agricultural scientists in their studies of plant and animal diseases due to deficiencies of essential elements, particularly the trace elements. Classification of soils by the Soil Bureau, especially into soil suites, has pointed to areas likely to have acquired soil deficiencies. This has enabled experiments, designed to overcome and to avoid these deficiency diseases, to go ahead with the minimum delay and wasted effort. This applies particularly to deficiencies of cobalt and molybdenum. Farmers in consultation with agricultural scientists, knowing the soil types on the farms, can decide fairly accurately on which paddocks trace elements may be applied with safety and economy.

Let us now consider some of the more outstanding features of the trace elements important in New Zealand farming.

A. THOSE APPARENTLY NEEDED ONLY BY ANIMALS

(1) *Cobalt.*

A deficiency of cobalt has been shown to be the cause of an anaemia in sheep and cattle, a disease which in certain districts has been known as bush-sickness. Cobalt seems necessary for the proper functioning of the rumen. The soils in which cobalt is in short supply, and on which bush-sickness has been reported, are chiefly those derived from rhyolite ash deposits and granite, both kinds of rock being of similar composition. The pumice deposits cover the central North Island, extending eastward to Matawai near Gisborne, and to north-western Hawkes Bay, west to Taumarunui and north to near Putaruru and to Tauranga. Granite soils occur at Glenhope in the Nelson district. The disease also occurs in Southland on soils derived from old sedimentary rocks called greywacke. Pastures on these soils grow normally but contain only about .07 parts per million of cobalt, while healthy pastures contain on an average .106 parts. Stock recover when drenched with a cobalt solution—in the case of sheep the tiny quantity of 1 milligram of cobalt per week suffices. Topdressing bush-sick soils with superphosphate containing 5 oz. of cobalt sulphate in each hundredweight also overcomes the disease.

Deficiencies in the above-mentioned areas are those inherited from the parent rocks. Induced deficiencies are occurring in

Canterbury. On soils where formerly sufficient cobalt was available to carry one ewe per acre there is now insufficient owing to liming and phosphating having trebled the carrying capacity of the land.

(2) *Iodine.*

Broadly speaking the iodine content of the thyroid gland of sheep is correlated with the iodine content of the soil. Outbreaks of endemic goitre are most liable to occur where this element is present in low amount in the soil. However, different plants and strains of plants vary in their abilities to take up iodine. For example, short rotation ryegrass has a low iodine content compared with its parents, pedigree perennial ryegrass and pedigree Italian ryegrass. There may be, too, some variation between districts as to the amount of iodine received by plants from the atmosphere.

Iodine cannot be applied as a fertiliser because iodine itself and its salts volatilise. Deficiencies are overcome by providing potassium iodide either in stock licks or in stock drenches.

B. THOSE NEEDED BY BOTH PLANTS AND ANIMALS

(3) *Molybdenum* is needed by plants for two reasons, (a) in protein building from nitrate, a part of photosynthesis, (b) in fixing soil atmospheric nitrogen by rhizobium and by azotobacter.

Soils deficient in molybdenum are widespread throughout New Zealand including many soils in North Auckland and the great area of soils, such as the yellow-brown earths, derived from greywacke rock, and making up much of the hill country in both the North Island and the South Island.

Providing there is an appreciable amount of inherited molybdenum in a soil, liming makes the molybdenum available. Where the inheritance is poor, molybdenum added at the rate of from one-sixteenth oz. to 3 oz. per acre along with phosphate and lime may increase production markedly. In some cases, and this is valuable on hill country soils that can be topdressed only from the air, molybdenised superphosphate with only a little lime produces such a good response that such country can be prevented from deteriorating and even be brought to a good level of production. Great care must be taken that molybdenum is not applied where it is not needed, or in too great an amount, or too often, or without applying copper sulphate as well where copper deficiencies exist also. Otherwise the livestock may be seriously affected by excess molybdenum in their diet.

(4) *Copper* deficiencies in soils occur almost exclusively with certain peats. Pastures on most peat soils need from 5 lb. to 30 lb. of copper sulphate per acre applied along with the required amounts of lime, phosphate, and potash. Vegetables and farm crops need 10 lb. to 30 lb. of copper sulphate per acre. Pasture on peat can be quite healthy and vigorous but the animals grazing that pasture can suffer from copper deficiency. Copperised superphosphate applied to give 5 lb. of copper sulphate per acre alleviates the stock trouble.

(5) *Manganese.* Deficiency of manganese may occur on heavily limed soils, and has been noted in various vegetable crops. The trouble has been cured by applying sulphur to increase the acidity of the soil. Where a soil is too acid, manganese toxicity may occur and the cure is to reduce the acidity by liming to raise the pH to about 6.

Mottled leaf of citrus trees has been cured by spraying with a solution containing managnese sulphate at the rate of 5 lb. per 100 gals. of water.

(6) *Magnesium.* Where serpentine superphosphate is used magnesium deficiencies are not likely to occur. Deficiencies of magnesium so far published in New Zealand have been those induced by excessive potassium applications and have been noted in fruit trees, tobacco and glasshouse tomatoes. Spraying the plants at the rate of 2 lb. magnesium sulphate per 100 gals. of water overcomes the trouble.

Unthrifty apple trees in the Nelson district have improved considerably by the application of magnesium sulphate to the soil.

C. THAT TRACE ELEMENT APPARENTLY NEEDED ONLY BY PLANTS

(7) *Boron.* The brown heart of turnips and internal cork of apples can be cured by topdressing with borax at 20 lb. per acre, usually as borated superphosphate. The soils of Nelson where brown heart and internal cork occur are very low in boron—dilute acid extracts much less than one part per million of boric acid, and similar figures are obtained in Central Otago where internal cork is prevalent.

Soils derived from serpentine rock in other parts of the world are infertile because of their high content of *chromium* and there is no doubt that some of our ‘mineral belt’ soils in Nelson and Western Otago contain toxic amounts of this element.

LIME

A broad definition of lime is that it is a compound of the element calcium which will reduce soil acidity. As we discussed in Chapter 11, the acidity of soil is closely related to the elements calcium and magnesium in their ability to saturate the cation-exchange colloids, to supply elements essential to plant growth, and to improve soil structure. Because cations, especially calcium are continually being lost from soil by leaching, it is necessary to restock regularly the calcium of the soil reservoir. Chemicals other than lime could be used to neutralise soil acidity, but lime is used because of its abundance and its cheapness, and because it supplies the essential element calcium and often also magnesium and possibly some trace elements such as molybdenum.

OCCURRENCE OF LIMESTONE

There are few farming districts in New Zealand which are remote from workable deposits of limestone. It is usually quite easy to recognise limestone country by outcrops such as rounded, hummocky landscape forms and cliff-like formations and by sink-holes and caves.

The papa rock of New Zealand is sometimes a true marl, that is, a mudstone containing a quantity of limestone (calcium carbonate). This explains why on certain papa slips new vegetation speedily covers the faces, and in this growth legumes are prominent. Apart from this case, it is the exception to find soil with a perceptible quantity of lime. This may seem strange in view of the numerous outcrops of limestone in various parts, but soil analyses have proved again and again that limestone in the subsoil does not necessarily mean lime in the soil, for lime is continually working downwards. Indeed in much limestone country it is found advisable to lime the soil.

QUALITY OF GROUND LIMESTONE

All agricultural limestones in New Zealand are regularly sampled and tested for purity and fineness of grinding. Some limestones are hard to grind, others easy; some are brightly coloured in pink or yellow tints, others are brown or grey, but the quality of the stone is independent of these features.

The essential points in the purchase of ground limestone are the purity of composition and degree of fineness. The purity ranges from 75 per cent carbonate in poor quality to approximately 95 per cent in first-grade lime. If a quick, prompt action is desired, a finely ground material is necessary, but it will not last as long in the soil as a coarsely-ground limestone. Some of the harder limestones dissolve more slowly than the softer and so may need finer grinding. The finer the limestone is ground the more costly it becomes. Further there is usually no advantage in ultra-fine grinding chiefly because the lime as calcium bicarbonate washes out quickly in the drainage water. The desirable state of grinding seems to be that in which there is a large variation in particle size so that there will be both rapidity of action and long continued action.

Exercise 4.—To get a rough comparison between samples of several different kinds of limestone:—Take equal weights of the samples, to each add a definite volume of dilute acid and leave until all fizzing has stopped. The amounts of residue left will give an indication of the relative freedom of the limestones from non-carbonate impurities.

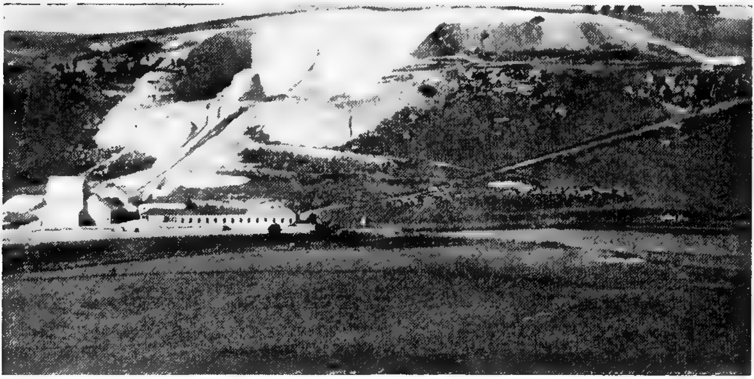


FIG. 70. Limeworks at Cormacks, North Otago. The limestone of these outcrops is of high quality (*N.Z. Journal of Agriculture*)

DISTRIBUTING GROUND LIMESTONE

The application of ground limestone may be from a few hundredweight to a few tons per acre, according to the character and acidity of the soil. The application offers no special difficulty or unpleasantness, and it may be distributed with a spreader. As ground limestone is such a bulky material, the use of mechanical aids in its transport and distribution has made possible the handling of the large quantities needed on many New Zealand soils. Giant stockpiles at railway sidings and at other strategic points, loading and unloading machines, and bulk spreaders enable the transport systems to be used and the spreading to be done evenly throughout the year.

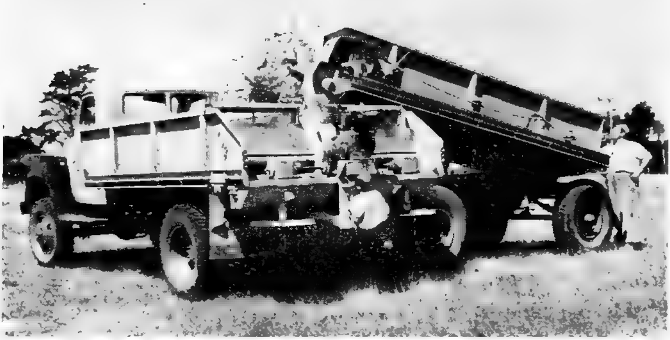


FIG. 71. Bulk topdresser being automatically loaded by its trailer after the initial load has been spread on the paddock

(By courtesy Domett's Lime Co., Ltd.)

Quicklime, known also as burnt lime, caustic lime and Roche lime, is chemically calcium oxide. It is sold in hard, whitish-grey lumps, or ground fine for agricultural purposes, is somewhat caustic or burning to handle, and breaks down into a powder or 'slakes' on the addition of water, heat being given off as the slaking occurs.

It is manufactured by heating, generally limestone, sometimes shells, in a specially constructed kiln. The purity or quality of any sample will depend upon the quality of the limestone used, and the thoroughness with which it has been burned. Almost all the high quality quicklime produced in New Zealand is put to uses other than application to soil. Unburnt stone and partly burnt stone along with over-burnt stone is sorted out from the contents of the kiln and ground up to make agricultural burnt lime, the rest being of high quality. The freshness of the lime is also a matter of some importance, since exposure to air, and especially to damp air, causes a gradual slaking, and finally if left exposed to the air over a considerable period a return to limestone or carbonate.

Quicklime should be stored so as to be well protected from rain or entrance of water. The action of water in slaking lime results in the production of much heat, and the heat so caused has at times resulted in the destruction by fire of farm buildings. During the 1917 floods in Otago, New Zealand, farm buildings were burnt when surrounded by water which found access to stores of quicklime.

Slaked lime results from the union of water with quicklime. The result is a whitish-grey powder, which is distinctly caustic. The main use for high quality slaked lime in agriculture is for spraying material, e.g., Bordeaux Mixture.

Exercise 5.—Solubility of lime. (1) Make water solutions of (a) slaked lime, (b) ground limestone. Filter, and to each add a little ammonium oxalate. A white precipitate indicates the presence of water-soluble lime. (2) Pass carbon dioxide through lime water till milky. The white precipitate is calcium carbonate, and of the same composition as the ground limestone. Continue passing the gas. A stronger solution of the gas dissolves the precipitate. In a similar manner the carbonic acid in the soil is capable of dissolving ground limestone.

COMPARATIVE VALUES OF THE VARIOUS FORMS OF LIME

When quicklime, slaked lime, and limestone are all obtainable, the question arises which will be the best to purchase at the price offered? When the various forms are free from impurities, 56 lb. of quicklime is the equivalent of 74 lb. of slaked lime, and of 100 lb. of limestone. Analyses of many samples of New Zealand commercial burnt lime show on the average 1 ton of burnt lime is equivalent to 1⅓ tons of limestone containing 90 per cent calcium carbonate. When freight and haulage are of little consideration, the quicklime should not be purchased if it is much more than one and one-third times the price of good limestone. When freight and haulage have to be considered, then an additional factor seems to be in favour of quicklime for hauling 1 ton of pure limestone involves hauling eight and four-fifths cwt. of the gas carbon dioxide. However, most burnt lime sold for treating soil is only a little if any better in total calcium oxide equivalent content than high grade ground limestones containing 90 per cent or more of calcium carbonate. Further, the difference in price in favour of ground limestone is so great that 'there can be no question that the unburnt (ground) limestone is by far the most economic liming material available to the farmers of New Zealand.' In general, quick or slaked lime is to be preferred only when the objective is to control the disease of swedes and other crops of the cabbage family known as 'club-root'.

Ground burnt lime is unpleasant to handle, both for men and horses. It is most conveniently and uniformly spread by employing a lime spreader or fertiliser drill fitted with suitable attachments.

In most soils the tendency of all forms of lime is to sink, and therefore they should not be ploughed under. On cultivated land liming should be one of the last operations, although some prefer to incorporate the lime with the first three or four inches of the soil, this being done by spreading on ploughed land and then harrowing in. If spread on the surface of pasture lime will be washed in readily enough by rain. In peat soils, however, the lime must be thoroughly mixed with the soil before sowing.

THE MISUSE OF LIME

There is a use and a misuse of lime; it can be employed to increase crop production, and it can also be so used that soil impoverishment must undoubtedly follow. Although ground limestone is not so easily misused as quicklime and slaked lime it can cause trouble if used in excessive amounts as we have observed in this and in previous chapters.

The quick and slaked limes, the more active forms, should never be applied in excessive amount, e.g. 5 tons an acre. This caution is hardly worth stating, except in respect to market gardeners, as in general the cost precludes excessive use. It probably is better to make light applications frequently, say once every year or two, than large applications at longer intervals. It is well to be cautious in using burnt lime when the organic content of the soil is low or cannot readily be increased or renewed. The position is well stated in the ancient rhyme—

> The use of lime without manure,*
> Makes both farm and farmer poor.

---

* The original reference is to farmyard manure and burnt lime.

Exercise 6.—Simple fertiliser trials may be carried out along the following or similar lines:—(a) To find whether or not potatoes on your soil need potassium (K) as well as phosphorus (P) and nitrogen (N), using sulphate of potash, superphosphate and sulphate of ammonia. Plant several rows of tubers with the fertiliser mixture in the drills with the tubers so that one row in 3 or 4 has N and P only, the rest N, P, and K. Weigh the produce from the two treatments and compare production from the average plant in each treatment. (b) To find whether or not swedes on your soil need molybdenum:—Sow several rows of swede seed with fertiliser just below and not in contact with the seed. Use molybdenised superphosphate except in every 3 or 4 rows have one row with superphosphate only. Weigh the produce from the two treatments and compare on an equal area basis.

READING

(a) General:—

Rural Education Bulletin, Oct. 1957

Canterbury Chamber of Commerce Agricultural Bulletin, No. 316

N.Z. Journal of Agriculture, Dec. 1951, Dec. 1956, May 1952, Feb. 1951, July 1946

Commercial Fertilizers and Their Basis of Sale, Bruce

Primary Production in New Zealand

(b) Phosphorus:—

Rural Education Bulletins, Feb., Mar., April, May 1948

N.Z. Dairy Exporter, Sept. 1957, June 1957

N.Z. Journal of Agriculture, Aug. 1957, Oct. 1953, Oct. 1952, Apr. 1952, Mar. 1952, Feb. 1951

(c) Nitrogen:—

N.Z. Journal of Agriculture, Aug. 1955

(d) Potassium:—

N.Z. Journal of Agriculture, Feb. 1957, Jan. 1955, Mar. 1952, Feb. 1951

(e) Sulphur:—

Canterbury Chamber of Commerce Bulletin, No. 324

N.Z. Journal of Agriculture, June 1957, Dec. 1956, Jan. 1956, Nov. 1954

(f) Trace Elements:—

Canterbury Chamber of Commerce Bulletin, No. 284

Rural Education Bulletin, July 1953

N.Z. Journal of Agriculture, Sept. 1955, July 1955, June 1955, July 1954

(g) Molybdenum:—

N.Z. Journal of Agriculture, Aug. 1957, July 1957, Apr. 1957, Feb. 1955, July 1954, Dec. 1953

(h) Copper:—

N.Z. Journal of Agriculture, Dec. 1956

14

The Selection and Valuation of Fertilisers

THE available supply of one or other of the essential minerals is often the limiting factor in plant growth. Another way of stating this principle is the *Law of the Minimum* first enunciated by Liebig. This Law states:—'The yield of a crop depends upon the "available" supply of that essential element of plant food which is present in least amount.' Hence this law implies that no superabundance of plant food in respect to one or several elements can compensate for deficiency in any one essential element.

If we consider only the four important elements—nitrogen, phosphorus, potassium and calcium—we find instructive instances of the working of the Law of the Minimum.

Thus:—

(1) A dressing of superphosphate gave an increase of 2½ cwt. of hay per acre.

(2) A dressing of ground limestone gave an increase of ½ cwt. of hay per acre.

(3) A dressing of both superphosphate and ground limestone in the same quantities as previously, gave an increase of 12⅕ cwt. per acre.

In fact, the total increase due to the two substances used on separate areas is only 3 cwt. of hay, but when applied together to the same land, an increase of 12⅕ cwt. is shown. From these figures it is seen that the land is deficient in both phosphorus and calcium—the substances supplied by the two materials. When only one substance is employed, the increase is insignificant, for an element is still in deficient quantity, and this substance determines the yield. It becomes clear that weakness in any one link of a chain cannot be compensated for by strengthening other links. The state of affairs indicated by the above figures often exists in respect particularly to the requirements of mangels and potatoes, so that it is often necessary to supply two, or possibly three of the important plant foods. It also happens, but less frequently, that pasture, cereals and fodder crops, such as rape and turnips, also require more than one fertilising ingredient to ensure the highest yields.

The law indicates the necessity of finding the weakest link in the chain of the conditions of plant growth. This weakest link can be discovered only by careful observation of the way the fields respond to various kinds of treatment.

FACTORS IN THE CHOICE OF A FERTILISER

Knowing from experiments the requirements of a soil for essential minerals, there are four main considerations which demand attention:—

1. *The Chemical Composition.*—What mineral substances does the fertiliser contain, and in what quantities?

The answer to this double question is of particular importance in respect to proprietary fertilisers, which vary in composition at the will of the manufacturer. The composition of two mangel fertilisers as shown below indicates the necessity, when purchasing fertilisers, of going beyond the name, and of making enquires as to the composition.

Fertiliser No. 1—Nitrogen (insoluble), 6.6 per cent.
Insoluble Phosphate (equivalent in tricalcium phosphate), 38.3 per cent.
Potash, 0.5 per cent.

Fertiliser No. 2—Nitrogen (insoluble), 1.75 per cent.
Insoluble Phosphate (equivalent in tricalcium phosphate), 32 per cent.
Potash, 1 per cent.

2. *Availability of Food Substances.*—A second factor which should receive weighty consideration in the purchase of fertilisers is the availability of the plant foods present. This we have considered in Chapter 13.

3. *Acid and Alkaline Fertilisers.*—A third important consideration in purchasing fertilisers is their effect on the ‘sweetness’ of the soil. Some fertilisers, e.g. sulphate of ammonia, dried blood and urea, are acid in their action. They make the soil more acid than it was before they were applied. Other fertilisers, such as basic slag and nitro-chalk, are alkaline in character, their effect being to counteract acidity, and hence reduce sourness.

A third class, known as neutral fertilisers, of which bonedust, and superphosphate are examples are neither appreciably acid nor alkaline in their effects so that their use carries with it the assurance that no harm will be done due to increase of soil acidity no matter what the original nature of the soil.

4. *The Type of Crop*.—To some extent also the type of crop will determine the kind of fertiliser. For example, potatoes can tolerate, and indeed require, a certain degree of acidity to check tuber diseases such as scab. As playing greens require fine-leaved grasses and no clovers, their fertilisers should be such that they work towards lowering the pH of the soil.

Other factors in the choice of a fertiliser are:—

5. Its suitability for aerial topdressing, e.g. whether or not it is granulated;

6. its keeping qualities, e.g. whether or not it sets hard in storage;

7. the evenness with which it can be spread; and

8. the ease and comfort with which it can be handled.

THE VALUATION OF FERTILISERS

With the large number of proprietary fertilisers of all grades on the market it becomes increasingly important to adopt some simple method of valuation. If the composition of the various fertilisers were uniform the comparison would be a very simple matter. This, however, is not the case. While the selling value of a fertiliser will depend to some extent upon the fluctuations of the market, it depends primarily upon the amount of fertilising ingredient present. A fertiliser containing a higher content of phosphoric acid than another will under normal circumstances be valued proportionately higher. Seeing that this is the case it throws some light on the folly of buying low-grade cheap fertilisers. It is the fertilising ingredient that should be bought and not the bulk. Cheap manures entail extra cost in railage, cartage, and application. When making a comparison between fertilisers as regards fertilising ingredients it is helpful to consider *unit value*.

> *The unit value of a fertiliser is the price per ton of that fertiliser if it contained only 1 per cent of the fertilising ingredient*. There are two main aspects of unit value:—

(a) The current unit value as determined by the cheapest source of the fertilising ingredient.

(b) The unit cost calculated from the analysis and price of the fertiliser in question.

The current unit values may be determined by comparing the price and composition of fertilisers from different commonly utilised sources and fixing an average value as a basis with which to compare the fertiliser in question. In some countries these current unit values are published periodically as a guide to purchasers.

When estimating unit values it is necessary that the ingredients should be expressed similarly. For example the phosphate in superphosphate is generally expressed commercially as 'tricalcic phosphate', whereas in the newer concentrated fertilisers it is invariably expressed as 'Phosphoric acid' (P_2O_5).

Under the New Zealand Fertiliser Act of 1927, and the Fertilisers Amendment Act of 1948, the purchaser of a fertiliser receives with each lot of 5 cwt. or more a certificate on the lines of that shown below in summarised form. This certificate indicates the minimum percentage of the several fertiliser ingredients. Nitrogen is shown as (a) soluble in water, (b) insoluble in water; phosphoric acid as (a) soluble in water, (b) insoluble in water, (c) soluble in citric acid solution as prescribed (optional); potash as soluble in water.

In the case of a mixed fertiliser the nature of each material used for supplying the nitrogen, phosphoric acid and potash in the mixture has also to be shown.

The fineness of grinding has also to be shown for basic slag and rock phosphate, and the Act requires that not less than 80 per cent shall pass through a standard sieve having 100 holes per linear inch, i.e. 10,000 per square inch.

The amount and kind of fillers or diluent, if any is present, is shown on the certificate. These fillers are used quite legitimately, in many cases to improve the mechanical condition of the fertiliser, and allow it to run more freely through the drill.

As the law is at present, a seller does not break the law if he sells a mixture, which may have little or no fertilising value, provided he does not describe it as a 'fertiliser'. He could give it a name such as 'plant food'. Also, if a seller does not supply, with lots of 5 cwt. or more, the analysis of the material, a careful buyer would suspect the material to be either of poor fertilising quality or selling at too high a price.

INVOICE CERTIFICATE under "The Fertilisers Act, 1927". (Somewhat modified)

We, (Name of Firm), hereby certify that the Fertiliser sold by us this day, as above, being a quantity as stated hereon, is known as set out on the following Certificate, of which the registered brand under which it is sold is also stated. We also certify that such Fertilisers contain the percentages of fertilising ingredients as set opposite it and that such fertilising ingredients occur in the forms set out. We further certify the fineness of grinding as set out, where prescribed by regulations under "The Fertilisers Act, 1927".

(Name of Firm)

Registered Brand	Percentage of Fertilising Ingredients						Percentage in which Component Parts are Present									Filler or Diluent
	Nitrogen		Phosphoric Acid		Potash											
					Soluble in water %											
Name of Fertiliser	Soluble in water %	Insoluble in water %	Soluble in water %	Insoluble in water %	Sulphate	Chloride	Super 44-46%	Reverted Super	Serpentine Super	Sulp. of Ammonia	Muriate of Potash	Sulp. of Potash	Blood and Bone	Rock Phosphate	Fineness of grinding	
Superphosphate			20.15				100.0									
Reverted Super				15.00				100.0								
Serpentine Super				15.00					100.0							
Nauru Phosphate				36.50										100.0	80.00	
Ammoniated Serp. Super ..	6.50			10.00					66.67	33.33						
Borated Super			19.80				98.10									1.90% Borate
Cobaltised Super			20.15				99.73									0.27% Cobalt. Sulp.
Copperised Super			19.60				97.50									2.50% Copper Sulp.
D.D.T. Super			19.80				98.44									1.56% D.D.T.
Molybdic Super			20.15				99.94									0.06% Sod. Molyb.
Potassic Serp. Super ..				11.25		14.60			75.00		25.00					
Complete Manure 3-1-1 ..	4.12			9.00	9.60				60.00	20.00		20.00				

Making Practical Use of the Unit Value

In the majority of cases the purchaser will use the unit value in determining the relative value of two or more fertilisers of which he has received quotations. As an example:

No. 1—Basic Slag, 17 per cent P_2O_5 cost £15 per ton.
No. 2—Basic Slag, 20 per cent P_2O_5 cost £16 per ton.

Both 80 per cent fineness and 80 per cent citrate soluble. Bring both to their unit value, or cost per unit:

No. 1—1 ton containing 17% P_2O_5 costs £15 unit value
1 ton containing 1% P_2O_5 costs £15 ÷ 17 = 17/8

No. 2—1 ton containing 20% P_2O_5 costs £16
1 ton containing 1% P_2O_5 costs £16 ÷ 20 = 16/–

A comparison of the unit values shows No. 2 to be the cheaper.

It is manifestly impossible to compare the values of different fertilising ingredients, one with another, nor can we compare the values of the same fertilising ingredient if it exists in different forms, as in different nitrogenous and different phosphatic manures. We cannot, for example, compare the value of sugar and bread. At 3d. per lb. sugar might be cheap and bread dear. It depends also whether we are in need of sugar or wish to have bread. So it is with fertilisers.

A good deal of discrimination and some experience is necessary in correctly valuing fertilisers. Many certificates refer to both citrate-soluble and insoluble phosphates as 'insoluble in water'. True basic superphosphate would in this case be classed as insoluble along with the phosphoric acid in rock phosphate. It is therefore necessary to ascertain from the certificate the kind of fertilisers used in the mixture.

Equivalents

On many invoice certificates equivalents are quoted. In the majority of cases it is quite unnecessary, and is but a repetition of the previous quotation, and it leads to confusion. The equivalents are in all cases higher figures, and it is quite sufficient to deal only with—

Potash quoted as K_2O.
Nitrogen quoted as N.
Phosphoric acid quoted as P_2O_5.

The following figures may be found of use in calculating equivalents:—

Per cent of Nitrogen (N) $\times \frac{17}{14}$ = per cent of Ammonia (NH_3) equivalent.

,, ,, ,, Ammonia (NH_3) $\times \frac{14}{17}$ = per cent of Nitrogen (N).

,, ,, ,, Phos. acid (P_2O_5) $\times \frac{155}{71}$ = per cent of Tri-calcic phos. equivalent

,, ,, ,, Tri-calcic phosphate $\times \frac{71}{155}$ = per cent of Phos. acid (P_2O_5).

,, ,, ,, Potash (K_2O) $\times \frac{87}{47}$ = per cent of Sulphate of potash equivalent.

,, ,, ,, Sulphate of Potash $\frac{47}{87}$ = per cent of Potash (K_2O).

MIXING OF FERTILISERS

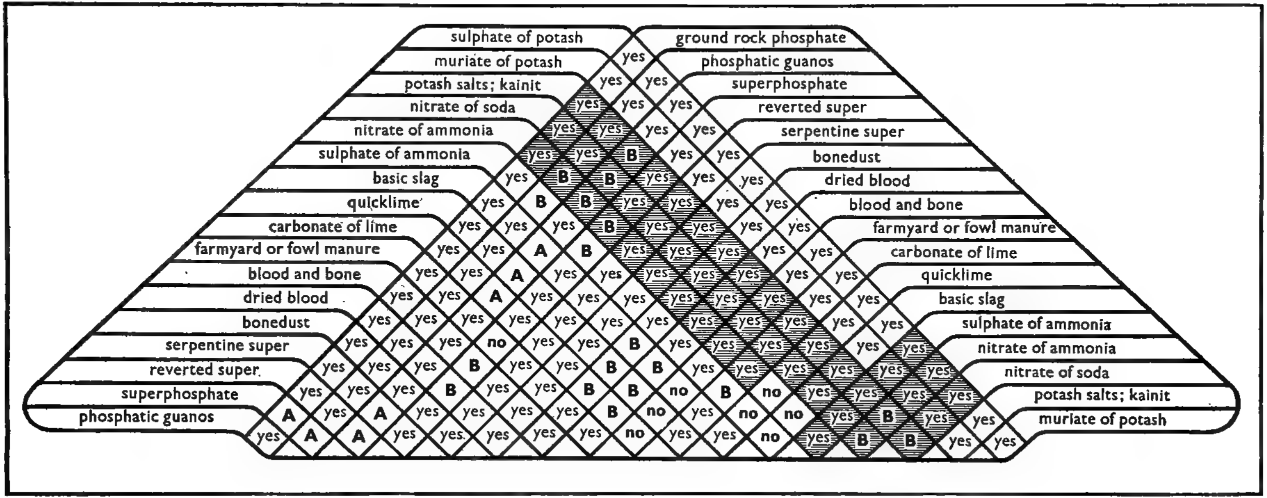
Instead of buying proprietary manures, which are at times unsatisfactory in respect of either quality, price, or a particular need, farmers may wish to make their own mixtures. The following precautions should be taken:—

(1) Basic slag, basic superphosphate, and burnt or slaked lime should not be mixed with sulphate of ammonia or any other fertiliser containing ammonium compounds, for the valuable ammonia would be set free and lost as a gas.

(2) Superphosphate cannot long remain mixed with any nitrate without setting free nitric acid—a result which is both wasteful of valuable nitrates and injurious to the bags and to anyone handling the mixture.

(3) Superphosphate, when mixed with quicklime or basic slag, will heat and set into a hard mass. This applies, to a lesser extent, with finely ground limestone. The best way to avoid this is either to use the manure immediately, or to turn over and well mix the manure at intervals till the chemical change ceases. Many farmers prefer to mix the manures in the drill while sowing.

Other mixtures which may and may not be made can be found from the diagram given opposite.



	ground rock phosphate	phosphatic guanos	superphosphate	reverted super	serpentine super	bonedust	dried blood	blood and bone	farmyard or fowl manure	carbonate of lime	quicklime	basic slag	sulphate of ammonia	nitrate of ammonia	nitrate of soda	potash salts; kainit	muriate of potash
sulphate of potash	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
muriate of potash	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	
potash salts; kainit	yes	yes	B	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	B	B		
nitrate of soda	yes	yes	B	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	B			
nitrate of ammonia	yes	B	B	B	yes	yes	yes	yes	yes	yes	no	no	yes				
sulphate of ammonia	yes	B	yes	B	yes	yes	yes	yes	yes	B	no	no					
basic slag	yes	yes	A	yes	yes	yes	B	B	no	yes	yes						
quicklime	yes	yes	A	yes	yes	yes	B	B	no	yes							
carbonate of lime	yes	yes	A	yes	yes	yes	B	B	no								
farmyard or fowl manure	yes	yes	yes	no	yes	yes	yes	yes									
blood and bone	yes	yes	yes	B	yes	yes	yes										
dried blood	yes	yes	yes	B	yes	yes											
bonedust	yes	yes	yes	yes	yes												
serpentine super	yes	yes	A	yes													
reverted super	yes	yes	A														
superphosphate	A	A															
phosphatic guanos	yes																

FIG. 72. Fertiliser-mixing diagram (*N.Z. Journal of Agriculture*)

Exercise 1.—Mixing of fertilisers—(a) Mix together sulphate of ammonia and slaked lime, sulphate of ammonia and slag. Smell the mixture in each case and decide whether any valuable ingredient is being lost. (b) Mix together superphosphate and nitrate of soda in a mortar. Notice the peculiar smell. Heat a little of the mixture on a crucible lid. The brown pungent fumes are nitrate fumes. (c) Mix together 1lb. of superphosphate and one half pound of slaked lime. When thoroughly mixed put it down and leave it for a few minutes. Note if there is any rise in temperature. Allow it to remain several hours without disturbing it. Is the texture altered? Test the solubility of this mixture and compare it with that of the original superphosphate. Test the acidity of the mixture. What are the advantages and disadvantages of mixing superphosphate and lime?

It may sometimes be possible for a farmer to save from 10/- to 15/- per ton on the price of mixed fertilisers by mixing them himself; on the other hand the merchant has a better knowledge of fertiliser mixing, and, having every convenience, is able to supply a better mixed sample than the farmer is likely to produce.

FERTILISER PLACEMENT

Considerable increases in yield of crop and saving of fertiliser can be obtained by accurately placing fertiliser just below or beside the crop seed when it is sown and sometimes while the crop is growing. This applies especially to phosphatic fertilisers which, in most soils, do not travel very far and which, in some soils, become 'fixed' or unavailable to plants. The accuracy of placement of fertiliser applies both to horizontal distance and to depth. Thus with a wheat crop it has been shown, using radioactive isotopes, that plants grown from seed drilled in rows 6 inches apart did not absorb phosphorus from adjacent rows. Grape vines growing in high 'fixing' soil did not respond to surface dressings of phosphate even when these were watered in, but did respond to the phosphate placed 15 inches below the surface.

READING

N.Z. Dept. of Agriculture Bulletin, No. 315

N.Z. Journal of Agric., Nov. 1953, p. 418, May 1952, p. 395, Apr. 1949, p. 324, Mar. 1948, p. 271

An Introduction to Agricultural Chemistry, (Chapter 10) Comber, Jones and Wilcox

A Student's Book on Soils and Manures, (Chapter 1) Russell, Sir E. J.

15

Tillage and Drainage

EUROPEAN methods of cultivation were introduced to New Zealand in 1820, when the first ploughing was carried out at Kerikeri, Bay of Islands. After about the year 1850 factory-made instead of hand-made implements became available. This resulted in a great increase in farm production per head. Thus the great expansion in cereal production of the 1870s in the South Island was made possible by the use of double-furrowed 3- and 4-horse ploughs, binders and grain drills. The next great forward move in the means of cultivating was the introduction and improvement of farm tractors, which have almost completely replaced horses. Since the year 1930 the number of farm tractors in New Zealand has increased about twenty-fold. Farm tractors have not only speeded up cultivation and enabled farmers often to 'beat' the weather, but also they have made possible deeper cultivation and drainage operations which could not be done by horses.

TILLAGE

Tillage is the art of working soil with implements to produce suitable conditions for plant growth. Soil conditions vary considerably. The art of the cultivator lies in his ability to so use the implements at his disposal on a particular soil that the best possible tilth is obtained. (See Chapter 11.) If he is working a heavy soil he must take advantage of the soil moisture content and of the changes in moisture content in the soil clods. He must know from experience when to cultivate and when not to cultivate, and what implements are best to use and how they should be used.

PLOUGHING

The object of ploughing is primarily to pulverise the soil, and to bury any weeds or organic matter that may be on the surface of the land. To bury the organic matter requires a plough that inverts the soil, and the use of a drag chain assists in the burying.

The use of a skim coulter greatly assists in the burial of surface growth especially when ploughing lea ground.

The following are the chief working parts of a modern plough:—(See the figure below).

1. *Share.*—The point penetrates the soil, and is hardened to prevent its wearing away too rapidly. The point dips slightly, giving the plough a certain amount of *suction*, or a tendency to drive into the ground. Cast-iron shares are usually discarded when worn, but steel shares can be beaten out and re-hardened repeatedly.

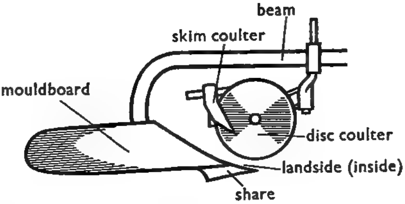


FIG. 73. The chief working parts of a plough

2. *Mould-board.*—This part turns the furrow slice. In the best ploughs it is made of soft-centre steel. The face is exceedingly hard, and takes a high polish after the plough has been used for a little while.

3. *The land-slide,* which takes up a great deal of pressure on the near side of the plough, is made of the same material as the mould-board.

4. *The beam or frame* carries the other parts.

5. *Coulter.*—This cuts a way before the share and mould-board.

6. *Land wheel* is used for regulating the depth of ploughing. Some ploughs are also fitted with a *furrow wheel* for regulating the width of the furrow.

Often it is a good practice to plough shallowly at first.

Skim-ploughing consists of ploughing to a depth of only two or three inches. The object is to turn over the sod and allow the grass to decay. A second and much deeper ploughing which follows in due course crosses the direction of the skim-ploughing, and cuts up and buries the more or less decomposed grass. Stubble land is also treated in a similar manner. Discing or skim-ploughing before deep ploughing is sound practice.

THE SUBSOILER

The subsoil plough is an implement made for the purpose of breaking up the subsoil without bringing it to the surface, where it would, under most conditions, be injurious to the germinating seed. It consists of a beam and a share but no mould-board, and usually follows in the wake of a single-furrow plough, breaking up the soil at the bottom of the furrow to a depth of 9 to 12 inches. This is particularly necessary where repeated ploughing at the same depth has produced a 'plough pan' and where iron salts have been precipitated to produce an 'iron pan'. Subsoiling is now rarely practised on the farm.

On small areas *trenching* or double-digging (Fig. 74) takes the place of sub-soiling.

TRENCHING—

Divide plot in two equal parts. A and B.
Dig C and remove to X.
Loosen and manure spit D but do not remove.
Shift E to C.
Loosen F.
Shift G to E.
Loosen H, etc.
Work to end of A, then top spit K will fill in J.
At finish the soil at X will fill space left at Y.

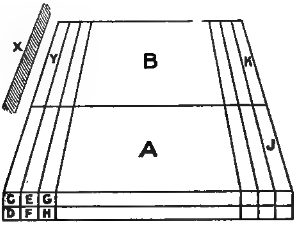


FIG. 74. Trenching

Plenty of room is needed for working, so make spit C about 2 ft. wide.

Advantages:—Deepens soil, allowing air and moisture to penetrate. Does not bring inferior subsoil to top. Best suited for lands with stiff subsoils.

CULTIVATION

Following ploughing further cultivation is usually required to produce a good tilth and to kill weeds.

The *disc harrow* is of value primarily because of its pulverising action. The discs, moreover, cut up and bury any weeds or rubbish on the surface, and leave a very fine seed bed and efficient mulch. The disc harrow may be used with great economy in the preparation of land for sowing grass after crops such as rape and potatoes, when ploughing would be too costly and often quite unnecessary.

Tine cultivators are on the market in almost endless variation. The value of the tine cultivator depends upon its ability to tear out weeds and form an efficient mulch. Weeds which will grow again when cut up and buried are more effectively eradicated with the tine than the disc cultivator. The tines do not bring about a great deal of pulverising. They break up the soil, and sift it to some extent, allowing the fine particles to fall through, and leaving the surface in a fairly cloddy or lumpy condition. A mulch of this type is an advantage in that it will take a considerable amount of rain to beat down the surface and make it set.

Smoothing harrows are made in a variety of forms. There are grassland harrows for spreading manure and more drastic types for opening up the pasture. The common tine harrows vary greatly in weight and strength and are used primarily for breaking down and smoothing cultivated land, eradicating young weeds and maintaining a surface mulch. There are spring tooth harrows adjustable for working to varying depths, while chain and brush harrows are used largely for covering grass seed.

Farm rollers are almost all of the Cambridge type and consist of a series of wheels forming a corrugated surface. This is an advantage in not leaving the surface of the soil smooth.

The object of rolling is to crush clods, and to pack and level off the surface of the soil. Rolling is also useful for breaking a surface crust formed by rain before plants are well established and for pushing stones below the surface and out of the way of harvesting implements.

THE EFFECT OF TILLAGE

The effect of tillage when properly carried out is to break up the soil into crumbs or granules. (See Chapter 10.)

Land that is ploughed when dry turns over in a cloddy state, and receives very little pulverising, but otherwise very little harm is done. If moderately heavy soils are worked while too wet the granular structure is destroyed, the soil is puddled, and dries into clods which are extremly difficult to bring back again into a favourable condition. The tramping of stock in wet weather may injure a heavy soil for many years afterwards. On the other hand there are soils of a light nature which are improved with just this treatment. There is a condition of wetness for every soil when digging, raking, harrowing, cultivating and ploughing that will bring down the soil to its best tilth. At this state a ball of loamy soil when moulded in the hands should fall to crumbs when lightly tapped. For other soils careful observation alone can determine this point.

Aeration of the soil is an important factor that results from tillage. The resulting increase in bacterial activity causes the liberation of plant food substances locked away in the organic matter of the soil. There may also be substances in the soil which inhibit the growth of plants, but which are rendered quite harmless when they become more highly oxidised. Plant roots and germinating seeds both require oxygen in the process of respiration, and it is only in a well-aerated soil that we can hope to have a healthy home for the ordinary agricultural plants.

MOISTURE CONSERVATION

This question is of paramount importance in nearly all agricultural districts. It rarely happens that a summer goes by during which we have at all times a sufficient supply of moisture for the growing crops. Crops transpire a large quantity of water, and if, at any period of their growth, the supply is insufficient it probably becomes the limiting factor in the yield to be obtained. Every endeavour should, therefore, be made to conserve the soil moisture. (See Chapter 10.)

BARE FALLOW

For the majority of crops it is advisable to commence preparing the land some time before the seed is to be sown. The land is usually ploughed as early as possible, and the rest that it then receives is termed a bare fallow. The effect of this practice may be stated briefly as follows:—

1. In dry climates the rainfall during the growth of a crop may not be up to requirements. It then becomes necessary to plough some time before sowing so that a large proportion of the rain which falls is conserved and is present in the soil at seeding time ready to augment that which falls during the growth of the crop.

2. During a fallow many plant food substances become available for the succeeding crop, notably nitrates. In very wet climates, as for example in the tropics, where decomposition of organic matter is very rapid, these nitrates are soon washed out of the soil. Under such circumstances it is more economical to substitute a fallow crop which utilises the nitrates and is ploughed in a few weeks before the sowing of the main crop. It must, however, be remembered that a mass of decomposing organic matter may have a harmful effect upon the germination of many seeds.

3. A loose and pulverised condition of the soil is not required by the majority of farm crops. A firm seed bed is often a very desirable condition, and once the land has been well ploughed it may consolidate and yet retain its good and friable tilth. The surface soil becomes 'sweetened' by exposure to the air, and forms an ideal seed bed.

4. Fallowing is a most efficient means of ensuring that a clean crop will follow. With the exception of certain weeds, such as Californian thistle, sorrel, and blackberry, the farmer has more to fear from the weed seeds in the ground than from the growing weeds. If land is ploughed, and a crop immediately sown, the seed will germinate and come up together with a host of weed seeds that have been brought to the surface, and which take immediate advantage of the favourable conditions. Plants like carrots and onions are immediately crowded out, and it often becomes impossible even to hand weed the rows. If the land is prepared and worked down to a moderately fine condition some time before the crop is to be sown, the weed seeds near the surface germinate, and can be immediately harrowed or cultivated out. Even after this, successive crops of weeds will appear, and the longer time over which the fallow extends the cleaner will be the succeeding crop. A modification of this method is the practice of growing 'cleaning crops' such as potatoes, maize and mangels, which receive a large amount of cultivation, and leave the land in a fairly clean condition. Weed seeds that are deep in the soil will rarely germinate, due probably to the presence of carbon dioxide in the soil atmosphere, but they retain their vitality for long periods. Crops which are likely to suffer from weeds should be preceded by bare fallow. Weeds have probably caused more failures in lucerne establishment in New Zealand than other causes. For this reason it is an advantage to sow the crop late in the season to enable a bare fallow to precede it.

DRAINAGE

THE OBJECTS OF DRAINAGE

The primary object of draining the land is to get rid of excessive moisture from in or on the soil. Some soils have open and porous subsoils, which afford perfect natural drainage. If, however, the soil and subsoil are of such a nature as to prevent the escape of excess moisture, the land will, under most circumstances, be profitably improved by drainage. The nature of the subsoil as well as the surface soil, influences the natural drainage of land. Sandy soils, for example, are usually well-drained, but an impervious layer of clay some distance below the surface will render the soil badly-drained, and often water-logged. The contour of the land will of course affect the drainage, many of the badly drained patches of soil on a farm being due to soakage from the higher land adjoining. This state of affairs can sometimes be corrected by laying out intercepting drains around the lower slopes of the high land. If deep, they will not only catch the surface water, but may also cut off a large percentage of the soakage.

The necessity for drainage is usually indicated by the appearance of sedges and rushes, and the general absence of the better pasture plants or lack of thrift in them. The glazed appearance of the furrow slice where it has rubbed against the mould-board of the plough is an indication of a wet soil usually resulting from bad drainage. There are many thousands of acres of ploughable land in New Zealand in which the limiting factor to higher production is drainage.

CAUSES OF WETNESS IN SOILS

Apart from the action of springs in wetting soils, wetness arises from two main and rather contrasting conditions. Pervious soils are often wet because of a *water-table* which rises to or near the surface during the winter and spring. This water-table results from the movement of water from higher country through sandy or gravelly strata well below the surface. The other main condition is where a fireclay or other impervious layer such as an ironstone pan occurs within a foot or two of the surface. If it is a clay pan this becomes so impervious when it is fully wetted that water cannot pass through it, and during the winter and early spring when evaporation is slow, rain accumulates in the soil above the clay and keeps it more or less saturated. This results in a *perched water-table.*

In the former case a hole dug to a depth of several feet will reveal the height of the water-table which represents the level of complete saturation. The water-table will usually rise and fall according to the rainfall, but this movement is only pronounced in a badly-drained soil. A great deal of damage is done to agricultural crops and fruit trees when the water-table rises nearly to the surface, and the plant roots are immersed in stagnant water. Such a state of affairs will never exist for any length of time if the land is drained, because when the water-table rises to the level of the drains the water is immediately carried away. Drainage, then, will lower the water-table, and allow the plant roots to penetrate to the depth of the drain.

In the case of a perched water-table the level of complete saturation fluctuates between the surface and the topmost zone of the impervious material which may be only a foot or so below the surface. Its presence is influenced mainly by water which falls directly on to it or runs off the surface of higher ground and not by movement of deep underground water.

OPEN DRAINS

Open drains or ditches dug to various depths are extensively used in draining land. This system is advisable, and indeed, necessary on peat soils which are consolidating and sinking year by year. Open drains are cheap to construct, but they have many disadvantages. They occupy a certain area of the land which can never be made use of. They obstruct the traffic on the farm, and necessitate the building of bridges. Clearing the sides and bottom of the drain becomes a very expensive item, and if not carried out, the drains become choked with vegetation which may encourage the spread of weeds around the farm. Broken banks are a constant source of trouble, and unless a good substantial fence runs down both sides of the ditch, stock are always liable to slip in, and are frequently unable to get out, unless gently sloping banks are provided at intervals.

TYPES OF UNDERGROUND DRAINS

The most satisfactory drains are made with pipes of unglazed burnt clay. The pipes have no collars, but fit closely up to one another at the bottom of the drain. They absorb water readily but water does not pass through their walls to an important extent—water enters almost entirely through the joints. All pipes are made one foot in length, and their measurement refers to the internal diameter.

POINTS TO BE CONSIDERED IN LAYING DOWN TILE DRAINS

1. Attempt to place the drains diagonally to the slope of the land unless the fall is very slight. The drains will thus intercept the main movement of water down the slope.

2. Never allow a steep grade to run into one which is markedly less steep; otherwise the lower pipes are liable to become choked with silt. If it is unavoidable, silt pans should be placed at the junction of the two grades.

3. The distance apart to lay the drains will depend on the nature of the soil and the rainfall and the use to which the land is to be put. Distances range from about 15 ft. for heavy soils under intensive use, such as where market gardening is done, up to 2 and 3 chains for more porous soils under sheep grazing.

4. The depth of the drains varies from 2 feet in heavy soils to 5 feet in lighter soils.

5. A grade of 1 in 500 is the least that should be allowed in ordinary agricultural tile drains. Open drains can be constructed and work well with only half this fall.

6. The size of the pipes will be determined by the area to be drained, the fall allowed, and the quantity of water they will be expected to carry at any one time. The usual size for paddocks is 3 inches or 4 inches diameter.

7. The drains should be laid out so as to drain uniformly the whole land, and avoid as much as possible having a large number of drains converging to one point, where the land will be unnecessarily well drained.

8. The main drains must be larger and deeper than the laterals. The latter should enter the main drain at an acute angle, and not at right angles.

9. It is always advisable to place a piece of wire-netting at the outlet, to prevent rats and other vermin from entering.

MOLE DRAINAGE

Mole drainage is a special form of drainage in which passages for the escape of excess water are formed in soils by the use of a mole drain plough. It is much cheaper than tile draining.

A mole drain plough consists of a frame which carries a wide thin blade 2 feet 6 inches to 4 feet in length and from 8 inches to

12 inches wide and ½ inch thick. The lower end of the blade carries a bullet-shaped torpedo which is drawn into the ground and along with it a plug or expander which shapes a round smooth channel. Mole drains are employed on land in which the subsoil is a heavy clay: in soils of loose open subsoil the walls of the mole drains are prone to crumble, and this leads to the blocking of the drains.

CONSTRUCTION OF MOLE DRAINS

No definite rules can be laid down as to the depth and the space between lines of mole drains. The following are important points to be observed:—

1. Place the mole drains in the subsoil, but not any deeper than is necessary to ensure that the comparatively crumbly surface soil will be avoided.

2. The distance between lines of mole drains that give efficient results is determined by the nature of the soil. The heavier the land the closer should be the drains, usually 6 feet to 9 feet apart.

3. Locate the pans by probing the soil with a suitable spear-like tool so as to avoid the pans in drawing the mole drains.

4. The size of a plug is 2 inches or 3 inches but it decreases with wear, and possibly the plug will have become so worn after it has been used in draining 30 to 50 acres that it will be advisable to replace it.

5. Dig a trench at the outlet of each mole drain until solid subsoil is reached, and then lay tiles from this point to the point of original discharge, and fill in the trench.

When the lower ends of a series of mole drains are along a slope, another, and probably more economical, means of ensuring efficient discharge is to provide an intercepting tile drain which should cross all the moles in solid subsoil, and which provides for the discharge of all water from the moles at a single point. This should be done as soon as the moles have been drawn.

6. Mole drains 8 to 10 chains long as a rule give good service, and they may safely be made longer provided there is a good and uniform fall throughout their length.

7. In mole drains it is particularly advisable to avoid the occurrence of level sections or of depressions, for these introduce the danger of gradual silting and eventual blocking of drains. Hence it is well to remember that the irregularities in the drain tend to conform to the irregularities of the surface of the land, and so it is necessary to go around instead of across depressions.

8. The formation of mole drains is usually best done in late winter after the rains have well moistened the subsoil.

THE BENEFITS FROM DRAINAGE

1. There is thorough aeration of the soil, fresh air entering when the stale air is expelled through the drains as the water sinks. Improved aeration in its turn

(a) Hastens the decomposition of organic matter, and the subsequent nitrification whereby the nitrogen is rendered available.

(b) Allows nitrification to continue at a greater depth.

(c) Causes the oxidation of substances in the soil such as ferrous (poisonous) salts to ferric (healthy) salts.

(d) Enables plant roots to enter to a greater depth; to the depth of the drains in many cases. Thus they have a greater feeding area, and are much more drought-resistant. Plant roots in undrained soil remain near the surface where they can get supplies of air.

2. The soil stays at a more uniform temperature. Owing to the removal of all excessive moisture the soil is much warmer in winter, and earlier in spring.

3. The removal of moisture from the surface enables the soil to be worked earlier after rain. Tillage operations are not delayed, and planting can be done at the proper time.

4. Water lying on the surface tends to destroy the granular structure of the soil. Rapid drainage, on the other hand, improves the granular structure.

5. Glasshouse soils and some irrigated soils become laden with injurious salts. The only satisfactory method of getting rid of these substances has been drainage and repeated flooding.

6. When soils are reclaimed from the sea they contain large quantities of common salt. If they are properly drained, the salt is steadily washed out through the drains.

7. Many diseases such as leaf-spot in lucerne and clovers, rust in cereals, 'sour sap' and canker in fruit trees, and foot-rot in sheep are checked.

8. Improved drainage of pasture land results in greater vigour of growth of the better species and in greater palatability of the herbage. Weeds such as sorrel, spurry, and sedges become less prominent.

READING

Farm Machinery and Tractors, (Chapters 1-3, 15) Cochrane, R. H.
Farming in New Zealand, (Chapter 5)
Mole Drainage in New Zealand, Hudson and Hopewell
A Student's Book on Soils and Manures, (Chapter 6) Russell
Elements of Agriculture, (Chapters II & V) Fream

16

Soil Erosion and Soil Conservation

Soil erosion is the accelerated loss of soil due to man's mismanagement of the land. It involves the flow of soil particles under the influence of water, wind and gravity. It must not be confused with geologic erosion which carved the landscape before it became stabilised by vegetation.

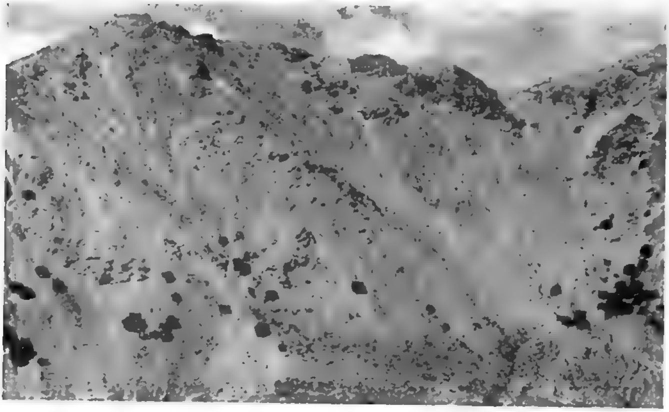
Land impoverishment through soil erosion is almost universal. For example, in China, as a result of erosion, the water of the Yellow River contains suspended solids up to about 60 per cent by weight, and in U.S.A. nearly one-fifth of the original area of tillable land has become so damaged by erosion as to make it unavailable for cultivation. In Iraq where 'eleven empires rose and fell over a period of 7,000 years' and where beautiful cities once stood, there are now only ruins and waste land. While erosion in New Zealand is not such a large-scale problem as it is in many other countries, it is one with which many New Zealand farmers have to cope and one of which every New Zealand farmer should be aware. Soil erosion is of national importance.

New Zealand's climate is good for farming but the high rainfall and the strong winds so prevalent over most of the country, together with the fact that more than half the farming land is very steep makes much of the country very prone to soil erosion. Hill country erosion is not confined in its effects to the hills, for the lowlands are made much more liable to flooding with its immediate destructive effects and with the covering of good land by sterile rubble. Moreover, owing to erosion reducing high-land production, the supply of store stock from highlands to lowlands for breeding and fattening becomes reduced. Those who study nutrition tell us that soil erosion is probably the principal cause of malnutrition. Depleted soils produce mineral deficient plants which will not adequately nourish animals and 'deficient plants and under-nourished animals will not support the people in health'. It is therefore clear that soil erosion has widespread effects.

Before Europeans settled in New Zealand, Nature had clothed the country in protective vegetation of great variety, mainly rain forest, beech forest, sub-alpine scrub, tussock and other native grasses, general scrub such as manuka and bracken fern, and swamp plants like raupo. With the help of axe and fire the settlers in 100 years cleared away about half the native forest and scrub and replaced it as far as possible with introduced grasses and clovers. Pasture then had to take over the role of soil protector.

FIGS. 75. and 76. Typical examples of soil erosion in New Zealand

(*Soil Conservation and Rivers Control Council*)



Nowhere is the principle of balance or equilibrium in Nature so clearly evident on such a large scale as is the balance between the forces of construction and destruction in a land area well clothed with vegetation. So our hill country, formerly in delicate balance between the soil conserving force of vegetation and the soil destroying forces of running water, frost and wind, tended to become unbalanced. Where the new pasture became established properly and remained dense and prolific, a new balance was set up and all was well. Mistakes however were inevitable. First, indiscriminate burning especially on the tussock country; second, attempts to turn too steep forest country into pasture land; third, over-grazing with sheep; and fourth, the liberation of grazing animals such as rabbits, which became pests. All have resulted in much unbalance followed by widespread soil erosion, sometimes of a very destructive type.

Soil erosion may be regarded as a disease of the soil mantle. It has symptoms or features by which it is recognised, it has a cause and a life history, it can be prevented, and, if it is not too far advanced, it can be cured.

The most obvious symptoms of soil erosion in hilly country are scarred hillsides due to *slips, mass flowage,* and *gullying.* (See Fig. 75.) Less obvious is *sheet erosion* or the imperceptible loss of thin layers of soil from the slopes. (See Fig. 76.)

On the more gently sloping land, especially where it is cultivated, *puddle erosion,* the loss of fine particles in muddy water run-off, and *rilling,* small gullies in cultivated hillsides, also occur. Then there is *wind erosion*, general throughout many areas and *stream erosion* where creeks and rivers meander in their courses and flood the lowlands.

FACTORS IN SOIL EROSION

To understand the causes of soil erosion it is necessary to understand the conditions to which soils are exposed, that is, the factors in soil erosion. The rapidity and extent of soil erosion is governed by (1) the slope of the land, (2) the nature of the soil, (3) the nature of the underlying rock, (4) the climate and (5) the management of the land.

(1) *The Slope*:—The steeper the slope and the longer the slope the greater is the velocity of flow of water down the slope, and therefore the greater the erosion. Thus, land of a 1 in 10 slope, under clean cultivation, may lose 20 tons or more of soil an acre a year.

(2) *The Soil*:—As we found when discussing soil in Chapter 10, the structure of a soil, a very important aspect of soil with regard to soil erosion, is largely dependent upon the supply of

organic matter in the soil. Clearing and burning of original plant cover, consolidation by the trampling of stock, and cultivation, all causing the dissipation of much organic matter, have resulted in the break down of desirable granular structure. The aeration of the soil and its capacity to hold water have therefore been reduced and run-off rather than absorption of water promoted. With a finely cultivated, bare soil, the surface compacts easily and forms a crust further increasing the run-off.

(3) *The Underlying Rock*:—The nature of the underlying rock has some effect on soil erosion. For example, the papa rock of the Poverty Bay Catchment District tends to assist slipping of the top-soil, and the unconsolidated sand of the Pohangina County in the Manawatu Catchment District is subject to severe gullying.

(4) *The Climate*:—Soils which are not adequately protected by vegetation have the forces of climate acting strongly in the direction of erosion. The greater the extremes of the climate and the less the protection of the soil the greater the tendency to erosion. Thus frost lifts and pulverises soil destroying its structure, especially on bare cultivated land during the winter; then heavy rains and high winds carry away the loose soil. Wind alone removes soil from cultivated land not sufficiently protected by shelterbelts of trees. This is common in central Hawkes Bay, Canterbury and the highlands. Periodic dry spells and droughts followed by heavy rain, conditions such as occur in the Poverty Bay Catchment, have promoted severe erosion on poorly protected hillsides. The low annual rainfall, concentrated in a few torrents, the abundant sunshine and high evaporation, the high winds, and the severe frosts and snows of the high country at Molesworth in Marlborough contributed in no small measure to the widespread soil destruction which the 320,000-acre sheep station suffered under mismanagement during the years between 1888 and 1938.

(5) *Farm Management*:—Farming factors which help to cause erosion, chiefly burning, grazing and cultivation, have produced major changes in vegetation and have increased greatly the capacity for action of each of the other factors of erosion, slope, underlying rock, and climate. Fire is a good servant but a bad master. It was useful in converting the less steep country from forest and scrub to farmland. The most serious drawback to the use of fire on farmland is the destruction wrought on the plant litter and soil organic matter with the resultant loss of fertility. Once

started a fire often cannot be stopped and may cause widespread destruction of protective vegetation, particularly of trees in gullies and on steep slopes. Highland tussock country in some parts of New Zealand has been reduced to desert due chiefly to annual burning of the tussock.

Overgrazing with sheep and cattle has had a marked effect in promoting soil erosion. Sheep, especially, being very close grazers and being often too highly concentrated have kept the shoot growth too short for adequate soil protection, and the root growth, consequently reduced as the shoots declined, has little value in binding the soil and maintaining granular structure.

Rabbits by their close grazing accelerate erosion in a similar way and also replace more useful animals. Fortunate are many farmers today that the efforts of the Rabbit Destruction Council have resulted in the rabbit pest being almost eliminated. Other pests, chiefly opossums, deer, wild goats, wallabies and wild pigs similarly must be controlled if destruction of trees and pasture is to be avoided.

SOIL CONSERVATION

Having considered the symptoms and the causes of soil erosion in New Zealand it is now pertinent to consider means of prevention, control and cure of soil erosion summed up in the term, soil conservation. The permanence of much land in New Zealand has been endangered where there has been ignorance of the dangers, the causes, and the preventability of soil erosion. Further, where the sole aim of farmers has been farm production with no regard for soil maintenance, that is where farmers have been 'miners' rather than husbandmen, permanence has been disregarded. Farmers hold their land in trust for the nation, so an important part of their duty is to ensure that farmland as a national asset does not deteriorate. There must be no procrastination. 'Never put off until tomorrow what can be done today' is an adage which holds most forcibly with soil conservation. Tomorrow never comes.

Soil conservation means treating land in such a way as to keep it permanently productive. It means that a farmer must study the problems of soil erosion on his farm; he must seek the help of soil conservation specialists to arrive at causes, prevention and treatment; he must then without delay implement the measures that are necessary for keeping his land permanently productive. He must also realise his responsibilities towards other farming land, especially if he is on hill country, for he must so manage his conservation that it fits into the needs of the catchment as a whole so that the problems of flood and river control of the lowlands may be overcome.

Soil conservation in New Zealand is under the direction of the Soil Conservation and Rivers Control Council and is administered by catchment boards of the twelve districts into which the country is divided.

Because farming generally has forced pasture to take over the soil protection formerly provided by the native vegetation, it is reasonable to consider first the means of strengthening pasture to give it good capacity to control erosion and conserve soil as follows:—

(1) *Topdressing* hill country mainly with phosphate, trace elements and ground limestone combined with *surface sowing* of clovers, all done chiefly by aeroplanes, is probably the greatest single factor in improving pasture for soil conservation on the hill farms of New Zealand.

(2) To be effective the topdressing and sowing must be backed up with closer *subdivisional fencing* to control the increased pasture growth, and also it must be backed up with other conservation practices.

(3) *Spelling* of pastures or relief from grazing for a period, depending upon the severity of the depletion of the pastures and the instability of the slopes, produces more shoot growth for ground cover and stronger roots for soil binding, and promotes spreading of the plants by re-seeding and tillering. The reduction of consolidation by trampling also increases the capacity of the soil to absorb water.

(4) *Rotational grazing with cattle* enables poor pastures to regenerate. Weeds are kept in control by being eaten or crushed, and, as cattle graze more leniently than do sheep, the pasture plants, especially the clovers, develop vigorously.

(5) In the low rainfall areas *pasture furrows* (or off-contour channels) conserve water and prevent erosion by collecting run-off water and directing it on to the spurs of the ridges which are normally very dry and poorly pastured.

(6) *Gully Erosion Control*:—To prevent gullies widening, deepening and working back into hillsides, the velocity and eroding power of running water in the gullies is reduced by the erection of *debris dams*. These are commonly made of live willow or poplar

poles driven into the ground, fitted with wire-netting across the upstream side to catch the debris, and with basal fascines to prevent undermining of the dam by scouring.

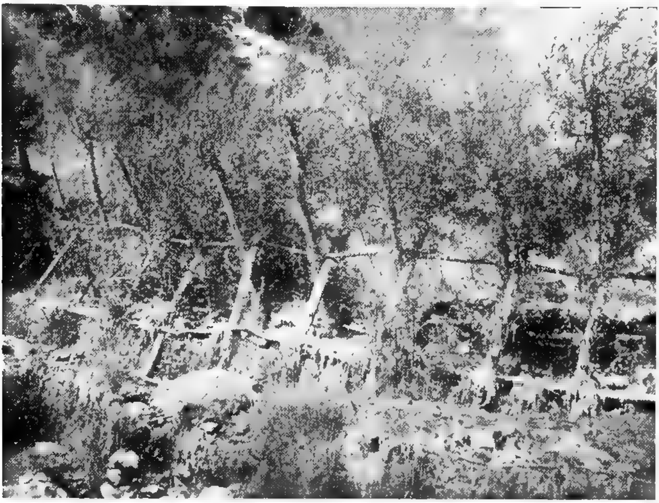


FIG. 77. A frame of willows and netting makes an effective debris dam for gully control (*N.Z. Journal of Agriculture*)

Also, if necessary and possible, the volume of water in a gully is controlled by the use of a *flood-discharge regulating dam* which can also be used for watering stock and for irrigating.

As prevention is always better than cure, it is wise to plant the banks of gullies, which are likely to erode, with deciduous trees such as willows and poplars. This is usually done in pairs at intervals, the length of which depends upon the degree to which the slopes are likely to erode.

(7) Similarly steep slopes liable to slipping and slumping are space planted with useful timber trees suited to the locality. (See Chapter 21.) The trees must be protected from stock and pests either individually or by fencing off the treed area.

(8) In order to provide cheaply and adequately for the tree planting it is desirable to have a tree nursery on the farm. Willow and poplar slips grow quickly and start to furnish poles suitable for planting in five or six years from establishment.

(9) By fencing off the steeper slopes and steep country generally from stock, and provided pests such as deer and opossums are eliminated, native forest can often be induced to regenerate within scrub. This is probably the only feasible way to deal with such country and is often a major step in the conservation programme for a catchment area.

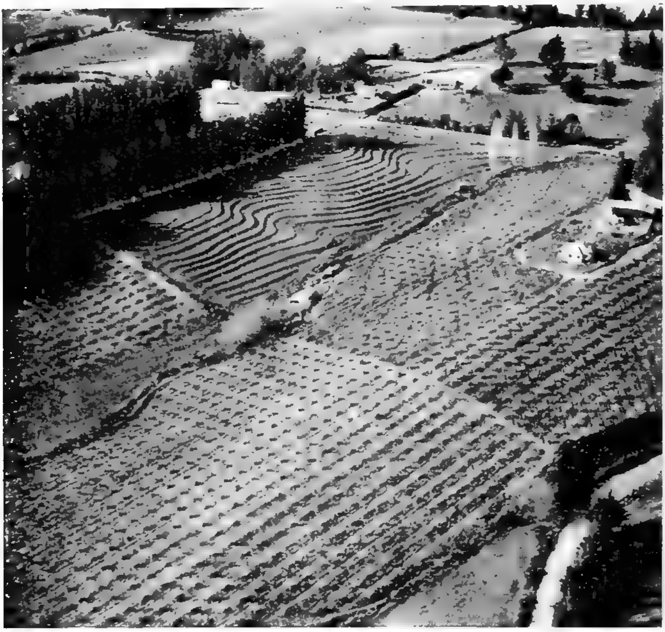


FIG. 78. Bench terraces minimise run-off and soil loss on steep orchard land at Appleby, Nelson
(*Soil Conservation Bulletin* No. 11)

CONSERVING PLOUGHABLE LAND

Contouring is the outstanding conservation practice on ploughable land. It means cultivating and planting along the contours of the hills in order to turn long slopes into short ones by various devices for promoting absorption of water, reducing run-off, and leading surplus water to safe discharge outlets. It includes the use of contour banks, graded banks, broad-based terraces, contour cultivation, strip cropping and grassed waterways.

Probably the greatest advance in land utilisation and land protection during recent years is the recognition of the fundamental law that farming must be adjusted to the physical limitations of the land, that land must be used 'according to the way nature made the land plus its condition resulting from the way man has used it'. Soil erosion is not inevitable. If a farmer is imbued with a love for his land, if he understands such teaching as is given in the parable of the talents, and if he makes use of the scientific information and services available, he need have no problems of soil erosion and he will ensure for posterity permanent productivity from the land.

READING

N.Z. Journal of Agriculture, Aug. & Oct. 1957, May 1948, Apr. 1946

Soil Conservation and Rivers Control Council Bulletins

Rural Educ. Bulletins, Apr. 1952, Aug. 1951, and Aug., Sept., Oct., 1950

N.Z. Dept. of Agriculture Bulletin, No. 263

Massey College Sheepfarming Annual, 1949

D.S.I.R. Soil Bureau Bulletin, 'Soil Erosion in N.Z.'

FILMS

(The National Film Library)

See the list given in *Soil Conservation Bulletin,* No. 11

17

Grasses, Clovers and Pastures

More than two-thirds of the land occupied by man throughout the world is covered with permanent pasture. It is therefore not surprising that pasture is the principal food of man's livestock. Man depends upon animals for important items of his diet, notably his 'protective' foods such as milk, meat and eggs which supply proteins highly necessary to his body growth and repair, and minerals and vitamins essential for his health.

New Zealand with nearly three-quarters of its occupied land in permanent pasture is in the forefront of pastoral countries of the world. Due largely to suitable climate, generally mild with well-distributed and generous rainfall, New Zealand is unique in the countries of the world with regard to permanent pasture. In no other country can pasture grow so well. 'New Zealand can grow nearly three times as much pasture feed for the same effort as in Great Britain, America and Europe'. In no other country do farmers rely so much upon pasture for their livestock. Under good management New Zealand pastures provide not only feed highly suited to the needs of our livestock but also the cheapest source of suitable feed, and they commonly do this all the year round.

Pasture is the physical foundation of our major rural industries. The return from animal products such as butter, cheese, milk powder, wool, mutton and beef constitutes more than 90 per cent of the export income of New Zealand.

As New Zealand, before European settlement, had only a few pasture grasses and no clovers, the early settlers brought seeds of the European pasture plants with them. Many of these plants were found to be very suited to New Zealand conditions.

IDENTIFYING PASTURE PLANTS

If we are to understand our pastures well, we must have good knowledge of the kinds of plants which make them up. There are three kinds of pasture plants, namely grasses, clovers and herbs.

GRASSES (Natural Order: *Gramineae.*)

True grasses which form such a large proportion of the meadow and pasture land of the earth belong to the order Gramineae, which also includes bamboo, sugar cane, pampas grass, maize, rice, wheat and the other cereals many of which are not generally considered as grass. On the other hand, the botanist excludes from the true grasses many plants which popularly are referred to as grass. This is usually because of the wider use in former times of the term grass to indicate any kind of small herbage. Hence the following plants are commonly confounded with true grasses:—cowgrass (better named broad red clover), ribgrass (plantain), knotgrass (polygonum), cuttygrass (sedge), nutgrass (sedge).

The plants most likely to be confounded with true grasses are sedges and rushes. Apart from great differences in the structure of the flower the following marks are of value for distinguishing grasses from all other plants:—

(1) The leaves are arranged in two rows alternately on the stem.

(2) The stems which are usually circular or flattened in section are never both triangular and solid. Maize and sorghum are grasses with solid stems.

(3) Usually, the stems branch only low down near the surface of the ground or below it. Some bamboos branch in the upper growth.

(4) The leaves are always without leaf stalks (exception—tropical bamboos). They pass below into the sheath which runs down the stem.

The roots of grasses are fibrous and arise from stems, there being no main root system developed from the roots which emerge from the seed. A new root system develops every growing season.

The stem of grasses is termed the culm, and is made up of a number of nodes and internodes. The nodes are thickened, and on them the leaves arise. The nodes are capable of growth after the internodes have matured. This character sometimes brings about the raising of culms that have been 'lodged', i.e., bent from the upright direction by wind and rain. The internodes are generally hollow. The culms of most grasses die down each year.

Frequent modifications of the stem are rhizomes and stolons. (See Chapter 3.) Some grasses have shoots which act as *false stolons,* in that they tend to spread along the ground rather than to grow erect. All these stem modifications are valuable in enabling grasses to gain possession of the ground by spreading when the plants are somewhat scattered. Grasses possessing rhizomes or stolons constitute 'twitches', and must be used with discretion on arable land, for these modifications result in such ready propagation that the eradication of twitches is often a laborious operation, e.g., couch grass (*Agropyron repens*), Indian doobj grass (*Cynodon dactylon*), smooth-stalked meadow grass (*Poa pratensis*).

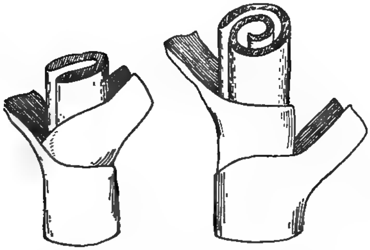


FIG. 79. *Left*: Folded leaf; *Right*: Rolled leaf

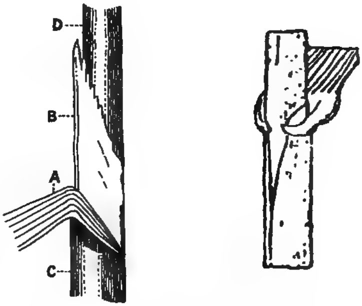


FIG. 80. *Poa trivialis*. A: Base of blade; B: Ligule; C: Sheath; D: Culm (x about 3) (*After Ward*) *Lolium perenne* (*After Percival*) Note the pointed auricles, the low ribs and the absence of hairs (glabrous)

Tillering, that is branching from buds at the base of a plant, is of common occurrence in grasses generally, and together with the development of underground stems is important in enabling grasses to cover the ground completely and form what is termed a sole. Cereals grown for straw or leafage should tiller considerably. Plants tiller more freely in light than in shade; hence thin sowing promotes tillering. Good soil induces tillering, as also does early sowing, and so winter-sown wheat tillers more than spring-sown wheat.

For some time after the stems have formed they remain with undeveloped internodes, enveloped by protecting leaf-sheaths. At this stage grazing or mowing is least likely to injure the stems or the ears by which they are surmounted.

Later on, 'shooting' takes place, i.e., the internodes extend rapidly and raise the ears out of the investing leaves. Cereal crops that are 'shooting' often become 'lodged' or 'lain'.

Leaves occur singly at the nodes, and are always arranged in two rows, i.e., the leaf at one node is on the opposite side of the stem to the one above or below, while the third leaf is on the same side as the first. This arrangement is sometimes obscured when the stem has twisted or has not elongated. A normal leaf consists of (a) the sheath surrounding the stem like a tube and usually split down one side. Old sheaths may persist at the base of the shoot, and their colour is useful for identification purposes. (b) the blade, which is often flat and nearly always many times longer than its width, i.e., linear. Blades and sheaths vary between species chiefly in shape and hairiness. The youngest leaf emerging from the top of a group of leaves is called the *leaf bud*. This may be either rolled or folded in the bud (Fig. 79), and is important for identification purposes. The blade possesses a strong central vein—the midrib—and a number of smaller ones called nerves, on each side parallel to the mid-rib. Leaves may be modified by reduction to scales or bracts. Reduced leaves occurring on a shoot below the foliage leaves, e.g., on rhizomes, are called scales. Those above the foliage leaves on flowering stems are termed bracts.

In most grasses there is a distinct boundary zone between blade and sheath. It is termed the *collar*, and is on the outside or back. On the inside at the junction of sheath and blade there is, usually, a membranous tongue-like prolongation of the former which clasps the culm. This is termed the *ligule* (Fig. 80). It varies much in appearance in different species, and is used for identification purposes.

In some grasses there occur, one on each side of the collar, claw-like appendages which wholly or partially encircle the stem. These are known as *auricles* (Fig. 81).

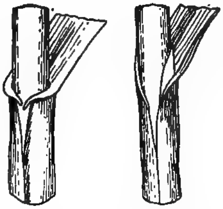


FIG. 81.
Left: Auricles present
Right: Auricles absent

The flower-head is made up of a number of units called *spikelets* consisting of clusters of flowers which may produce seeds. Some grass seeds have *awns* which are bristle-like projections, straight or curved.

The so-called 'seed' of grasses is, as a rule, a fruit. It is a *caryopsis* which consists of a single seed with a poorly-developed seed coat firmly fused to the seed box.

CLOVERS. (Natural order: *Leguminosae.*)

Included under this heading are the true clovers, and also the medics and lotus. Their flowers are all similar to the pea flower in general structure; their fruits are pods; they have trifoliate leaves, i.e. compound leaves each usually with three leaflets; and their roots have nodules containing Rhizobium bacteria capable of turning the nitrogen of the soil air into nitrates and proteins. A specially useful feature for identification is a pair of structures called *stipules* occurring at the base of every leaf stalk. They show great variation in the various species from the narrow, membranous stipules of white clover to the broad, leaflet-like stipules of lotus. (See Fig. 82.)

Exercise 1.—Examine at regular intervals in demonstration plots the common species of grasses and clovers. Make notes of such observations as:—(a) Features for identification. (b) Resistance to drought. (c) Response to autumn rains. (d) Resistance to frost. (e) Winter growth. (f) Time of flowering. (g) Persistency. (h) Recovery after grazing. (i) Palatability.

SOME FEATURES OF PASTURE PLANTS

In getting to know pasture plants the recognition of them by their features of external form, though an essential first step, is comparatively unimportant. Far more important features are:—their habit, rate of establishment, habitat, and their reaction to biotic factors.

(a) The *habit* of a plant means the form of its growth. It alters somewhat according to changes in the *environment,* the external conditions acting on the plant, but every plant has a normal or usual habit. For example, white clover has true stolons, *Lotus uliginosus* climbs or is procumbent, cocksfoot has its crown above ground level, snow grass is tufted. A pasture plant's habit affects its ability to survive in competition with other plants. Thus plants, such as phalaris, with their crowns below the surface of the soil are able to withstand close, continuous grazing better than those such as cocksfoot with their crowns at or above the soil surface; plants with rhizomes such as browntop grow best in loose soils.

(b) The *rate of establishment* of a plant is the rate at which the seed germinates and the seedlings grow. The rate of course varies with the environment notably the water supply, but different plants in any one environment establish at different rates. Italian ryegrass, for example, under conditions of high soil fertility, will usually become established very quickly smothering weeds, and also desirable plants like white clover, if care is not taken. A contrasting example is timothy which, in a young mixed sward, is soon smothered by ryegrass if the grazing is not carefully controlled.

(c) The *habitat* of a plant is the particular kind of environment suited to the plant. Every plant has its own range of habitat, varying from narrow to wide, within which it succeeds in competition with other plants. A pasture plant with a wide habitat range is cocksfoot, one with a small habitat range is strawberry clover.

There are various factors in the habitat:—(1) *Climate,* especially the rainfall and temperature aspects, determines the distribution of many pasture plants in New Zealand. Thus paspalum and prairie grass grow well only in the warmer parts of the North Island; alsike clover survives cold and so grows well at high elevation in the South Island.

(2) *Soil moisture* content, closely dependent upon rainfall, is a major factor in plant survival. Danthonia pilosa for instance is our best pasture plant for very dry soils; short-rotation ryegrass, on the other hand, is very liable to die in a dry summer, unless irrigated.

(3) The soil content of *elements necessary* for plant growth is often a factor determining the kinds of plants which succeed in a certain place. Thus clovers will not grow well in soil short of available potassium or of the trace element molybdenum. Ryegrasses, in contrast to say browntop, must have good soil nutrient supplies, especially nitrogen.

(4) *Light.* All pasture plants need light for photosynthesis, but they vary in their light requirements. Although there is no satisfactory method of determining the light requirements of the different kinds of plants in a community, observations of pasture plants indicate that some grasses and clovers can endure shade better than others. So, for example, in waste places subject to little or no grazing we often see cocksfoot to be the dominant plant; lotus major, a good shade endurer, will grow up through rushes and bracken fern.

(5) Lastly, we need to consider in the pasture habitat the *biotic factor,* that is, the influence of other living organisms on the plants:—parasitic fungi causing disease, e.g. rust; insect attack, e.g. grass-grub; the influence of grazing animals, chiefly

cattle, sheep and rabbits; the direct influence of the farmer in such activities as draining and topdressing. So important are the biotic factors in pasture habitats that the next chapter is largely devoted to considering them under the title 'Pasture Management'.

In the following classification and accounts of the chief pasture species and strains, reference is made to such of the above features as are applicable. Other important features may also be referred to, namely, seasonal production, palatability and longevity under normal farming conditions.

THE CHIEF PASTURE PLANTS OF NEW ZEALAND

NOTE:—The term 'fertility' in this classification includes all the soil conditions which affect plant growth. 'High fertility' means that the soils have sufficient supplies of water, air and nutrient elements, good structure, and freedom from harmful substances. 'Low fertility' means poor supplies or the presence of harmful substances or both.

A. GRASSES AND CLOVERS OF HIGH FERTILITY COUNTRY.

1. PERENNIAL RYEGRASS (*Lolium perenne*).—Perennial ryegrass is the most valuable grass species in both permanent and short rotation pastures. It grows best on loamy, stiffish soils that are fertile, well drained, yet not too dry, but it has a fairly wide habitat range. It is recognised by its red base, small ligule, small auricles and folded bud. Perennial ryegrass should always be included in permanent pasture mixtures, even on dry soils which cannot maintain it permanently, for it establishes itself very quickly, a feature which is important chiefly because weeds are checked.

It is the most valuable grass for first-class permanent pastures because:—(1) it is highly productive; (2) it yields well early in the spring and grows also in the winter; (3) the plant matures very quickly; (4) it is improved rather than injured by the tread of cattle, and (5) it blends in well with all other constituents of the permanent pasture, associating especially well with white clover. The main defect of perennial ryegrass is that it produces little or nothing in the dry summer period.

Due to the efforts of agricultural scientists (see the later section 'Pasture Strains and Certification') certified perennial ryegrass under suitable conditions can be relied upon to be permanent and to produce more highly than any other permanent pasture grass.

2. SHORT ROTATION RYEGRASS (*Lolium perenne x L. multiflorum*).—Short rotation ryegrass is a hybrid between true perennial ryegrass and true Italian ryegrass. It is distinguished from perennial ryegrass by having large auricles, rolled bud and awns on the head. Bred and produced by the Grasslands Division to serve as a major component for 3-4 year pasture within a short rotation cropping system it also serves as a winter-yielding component of special purpose pastures and as a constituent of permanent pastures for fat lamb and dairy production. It is intermediate in character between perennial ryegrass and Italian ryegrass with much of the persistency of the true perennial and much of the early vigour, good winter growth, and high palatability of the Italian ryegrass. Once the supply of available nitrogen has been built up in the soil, its good winter and early spring growth come to the fore. Largely due to its great palatability even in advanced stages of growth, great care must be taken that it is not grazed too hard, especially just after establishment and when it is dormant. Otherwise it will die out. Being more susceptible to dry summers than perennial ryegrass it often goes beyond dormancy to death. However, if it does die, it can usually be restored by sod sowing.

3. ITALIAN RYEGRASS (*Lolium multiflorum*).—Italian ryegrass is the most useful of the grasses of short duration. Usually it lasts no more than two years, except on land of a heavy nature devoted to cattle grazing, when, if allowed to seed, it perpetuates itself. It is difficult to distinguish from short rotation ryegrass. Like English or perennial ryegrass it has a shallow root system, and so does not withstand drought. While it will grow on almost any soil, it thrives only on highly fertile country. Loving warmth and moisture, it makes extremely rapid growth on rich damp soils, producing heavy crops in the same season in which it is sown. For permanent pasture mixtures it is useful because of its quick establishment but it should be grazed early, for it grows so rapidly that it is apt to smother other pasture plants. The pedigree strain of Italian ryegrass is vigorous, palatable, and a high winter producer. It is extensively used with red clover to form temporary pasture of one to two years' duration, and also associates well with pedigree white clover.

4. PASPALUM (*Paspalum dilatatum*).—This grass develops thick rhizomes and it has large ligules and flat buds. It grows well on any fertile soil where conditions are warm and, being

deep-rooted, it is able to withstand long periods of drought. It is essentially a warm-climate grass, and is eminently suited to the northern portion of the Auckland province and to some extent also to the rest of the province except the highlands. Unless well managed it takes almost complete possession, choking out all the other grasses and clovers, and forming such a compact turf that it is very difficult to dislodge, even with drastic cultivation. This habit tends to produce a pure paspalum pasture, which yields little or no herbage during the winter and spring. If, however, in association with ryegrass and white clover, it is properly grazed and autumn topdressed, there develops a pasture which may rank with the highest producing pastures in the world. Paspalum is extremely valuable on wet low-lying country within its climatic range, for the control of tall fescue and for the grassing of wet swampy areas that are too wet to carry stock in the winter. As the grass is rather slow to establish from seed, pure sowing of paspalum should not be made. Paspalum excels most rival summer forage crops such as maize and turnips, in that it is permanent, and can be pastured economically.

5. TIMOTHY (*Phleum pratense*).—A long, white and blunt ligule, a rolled bud, and a swollen stem base are the chief distinguishing features of timothy. It thrives well in clay districts and on moist soils, and is excellent on peaty soils. A little slow to establish itself, it reaches its maximum productiveness in the first or second year after being sown. As it matures late in the season, (a) it combines well with meadow foxtail and with perennial ryegrass in spreading seasonal growth, (b) where the spring season is usually too wet for haymaking, it makes good hay for late cutting. Being also a good producer, palatable and hardy, it is a valuable constituent of many permanent pastures.

6. WHITE CLOVER (*Trifolium repens*).—Distinguishing features of white clover are:—narrow stipules, smooth broad leaflets and true stolons. As with perennial ryegrass, white clover strains have been so improved that certified white clover is, over a wide range of conditions, a most valuable constituent of permanent pastures. Indeed for these it is the ideal legume because of its relatively high production, good nutritive value, ease of management, and suitability as a companion to other main pasture species. It is of particular value for its midsummer growth when other species are declining in yield.

To get good results in establishing white clover in permanent pasture, it is specially necessary to have a fine, firm seed-bed, the seed being small. Sowing should be done early in the autumn or in the spring because the seedlings are easily killed by frost and frost-lift; and the young pasture should be lightly grazed to prevent smothering of the white clover plants by quickly establishing grasses like short-rotation ryegrass. Provided the soil is not too acid, white clover commonly responds very well to phosphatic fertilisers. Because it has a creeping habit, it is very suited to sheep pastures which are often subject to very close grazing.

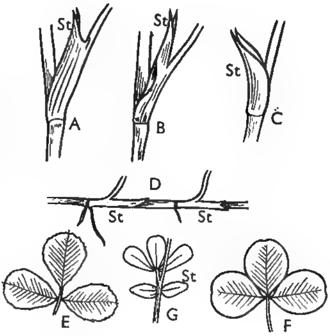


FIG. 82. A: Stipule of Red Clover; B: Stipule of Alsike; C: Stipule of Subterranean Clover; D: Stipule of White Clover showing roots arising at the nodes; E: Leaf of Burr Clover, typical of the genus *Medicago*. Note the midrib is carried past the bases of lower leaflets and a spike protrudes from the niche at the end of the leaflets. F: Leaf of White Clover, typical of genus *Trifolium*. No lengthened midrib and no spike at end of leaflets. G: Leaf of genus *Lotus*. The stipules are very similar to the leaflets. *St*: Stipules

7. **RED CLOVER** (*Trifolium pratense*).—Red clover of commerce consists of two main types:—(a) Broad red clover, which is also called early-flowering red clover and cowgrass. (b) Montgomery red clover. Both these types have their places in New Zealand pastures. Red clover is distinguished from other clovers by its large, abruptly pointed stipules and its hairy leaves.

Broad red clover is quick both to establish itself and to yield heavily. Added to this, it combines well with quick establishing grasses particularly Italian ryegrass and short rotation ryegrass. Hence it is eminently suitable for temporary pastures especially for winter production and for hay.

Montgomery red clover, which is more permanent, flowers later in the season than broad red, and is more suitable for use in permanent pastures. Its considerable value lies mainly in its rapid establishment, heavy yield of hay, and good yield in the latter part of the summer when other prominent pasture species decline in yield. If it is to last more than three years in a pasture, the soil fertility must be kept high, and continuous close grazing avoided.

B. GRASSES AND CLOVERS OF MEDIUM FERTILITY COUNTRY.

8. COCKSFOOT (*Dactylis glomerata*).—Because cocksfoot has a wide habitat range growing well on all but the wettest soils and the driest soils low in nutrient elements, it is one of the most valuable and commonly used grasses in New Zealand. Recognition of cocksfoot depends chiefly on its long ligule, folded bud and hairless condition. Having a fairly deep rooting system it is able to resist drought well and so is specially useful on somewhat dry, light, medium quality land. As it is rather slow to mature, it should not be used in pastures of less duration than three or four years, but should often be included in seed mixtures for permanent pastures. Within its habitat range the Grasslands strain is a vigorous and high producer of leafy herbage. While it is a fairly early spring grower, its good summer growth, usually not far behind its spring production, is the feature which makes it most valuable. If allowed to grow rank, cocksfoot will smother other pasture plants. On the other hand, owing to its crown being above ground level, too close and continuous grazing often causes it to be weakened and unable to compete with mat-forming grasses such as browntop. Such management should be specially avoided on unploughable country where it cannot easily be restored by resowing.

9. CRESTED DOGSTAIL (*Cynosurus cristatus*).—Somewhat similar in appearance to perennial ryegrass, it can be distinguished by its yellow basal leaf sheath. Although crested dogstail is rather low producing, it is one of the best sheep grasses on second class country. After flowering, the stems become tough and wiry and are rejected by animals, with the results that the seed is matured and dispersed freely. But for this it would probably disappear from pastures, sheep being so fond of it as to eat it down extremely close. However, as it will not stand shading, it soon disappears from cocksfoot dominant pastures which are lightly grazed. Establishing fairly rapidly it comes to maturity in the first year. What makes it valuable on sheep country is its winter and early spring growth. It is useful for lawn and pleasure grounds because it is one of the best of all 'bottom' grasses combining well with other grasses and filling in bare patches and thickening up the turf.

10. BROWNTOP.—Browntop is often dominant over large areas of second-class wet rather sour clay soils in both islands. It is distinguished from similar grasses in the vegetative stage by its very short ligule and its rolled bud.

Essentially a fine-foliaged, dense turf-making grass, with strong rhizomes, it is seldom sown in pastures on ploughable country. It appears as a successional volunteer after the species sown have run out or weakened owing to a shortage of nutrient elements, or to very close grazing or both. Browntop has proved a most valuable grass for wet hill country, and is the most valuable species for all manner of secondary growth burns where top-dressing cannot be carried out. Browntop is the most valuable grass for lawns and playing greens, some 250 tons of seed being produced annually and exported, mainly to America. For lawns and greens, it is usually combined with Chewings fescue in the proportion of one to two parts by weight and sown at the rate of half to one ounce per square yard.

11. SUBTERRANEAN CLOVER (*Trifolium subterraneum*).—With broad stipules, broad and hairy leaves, false stolons and pods turning into the soil, subterranean clover is easily distinguished from other clovers. It is the highest producing annual clover and is of outstanding value in districts subject to summer droughts followed by enough rain in late summer or early autumn to enable the subterranean clover to germinate and grow freely. Its use is not recommended under high fertility conditions where white clover will succeed. Growing mainly in autumn, winter and early spring, it matures seed early, and the plant dies out on the advent of hot weather. Lack of abundant pre-winter growth which occurs in a dry autumn greatly reduces the value of subterranean clover. In association with such a summer-producing grass as paspalum, which it does not injure by shading, it is productive when the paspalum is dormant.

Due to its habit of tiding over a dry period by dying and reseeding it plays an important role as a fertility builder in the lighter soils throughout New Zealand where fertilisers cannot be applied. While subterranean clover establishes quickly after the initial sowing it is necessary to allow for a plentiful supply of seed by so arranging the grazing that the newly sown area flowers and seeds freely in the early summer.

There are two strains used in New Zealand, a mid-season strain called Mt. Barker, and a late-season strain called Tallarook, the latter being more leafy and a better seed producer than the former. Mainly because of the difference in seasonal growth between the two strains, a seed mixture of the two in equal proportions is commonly sown.

12. Lotus Major (*Lotus uliginosus*).—Distinguishing features of lotus major are its leaflet-like stipules, hollow stems and a yellow flower-head with ten or more florets. A perennial 'clover', it gives its maximum yield on moist land. There are two kinds of farming land where it is a useful pasture legume, first on partly developed swamp country, and second on hill country of high rainfall especially where weed growth is troublesome. Due to its tolerance of shade lotus major is able to grow up through the weeds. Its presence among the weeds attracts cattle to the area and the weed growth tends to be kept in check by the eating and trampling of the cattle.

C. Grasses and Clovers of Low Fertility Country.

13. Danthonia.—Two species which are of importance in New Zealand farming, *Danthonia pilosa* and *Danthonia semiannularis,* occur in New Zealand, and both are natives. It is difficult to distinguish between them, but *D. pilosa* is less hairy in both leaves and head. Both species have very short ligules and long hairs at the bases of the leaf blades. *Danthonia pilosa* is much superior to *Danthonia semiannularis* from the grazing point of view, and its use is advisable in all hill country sowings liable to revert into fern and scrub. It is the best grass for third-class pastures, for it will grow and produce palatable feed in dry soils of low plant nutrient content where no other grass will survive.

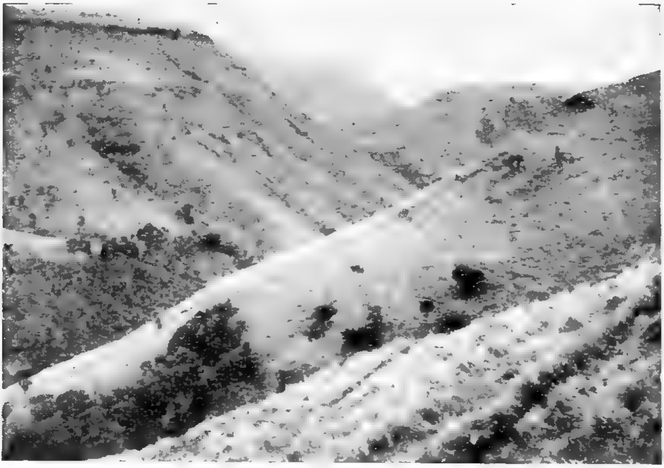


Fig. 83. Danthonia-dominant grassland

14. CHEWINGS FESCUE (*Festuca rubra,* var. *fallax*).—To recognise Chewings fescue among the common grasses you need only notice its needle-like leaf blades, its very small ligule, and its short, erect auricles. This is a low-producing grass flourishing under a wide range of conditions, and growing especially well on light, dry lands and on moist meadows. Being a bottom grass, twitchy and drought resistant it is well adapted for lawns and playing grounds. Associated with browntop it has no equal for this purpose. Stock relish it only when the growth is young. On good land it should not be sown, as it would occupy land which could carry species of higher yield and palatability. It has a place in farming on high country with cold winters and low summer rainfall.

15. YORKSHIRE FOG (*Holcus lanatus*).—Yorkshire fog is rightly classed as a weed where ryegrass and cocksfoot thrive, but it is of considerable value on many other pastures, mainly those belonging to the third class of fertility. Distinguishing features of Yorkshire fog are the very hairy leaf, large toothed ligule and pink veins on the basal leaf sheath. Outstanding features of its living are, (1) its growth chiefly in the winter and early spring, and (2) its mat-forming habit making it a good soil binder on unconsolidated peat and on shady faces of low fertility hill country. It is widely used on poor undrained swamp land and is of great value in the early stages of the improvement of peaty swamp land.

16. TUSSOCK GRASSES.—By tussock grasses is meant those native grasses which make up the dominant vegetation on what is commonly referred to as the native tussock grassland. There are about eleven million acres of this grassland, most of it in the South Island, comprising about one-quarter of the total occupied area of New Zealand.

The following are the chief species of native tussock grasses:—

(a) SILVER TUSSOCK (*Poa caespitosa*). About 1 ft. 6 in. high silver tussock has yellow, bristly, smooth leaves and there are no awns on the seed-head.

(b) HARD TUSSOCK (*Festuca novae-zelandiae*), is similar to and often associated with silver tussock on low tussock country which makes up about half the total area of tussock grassland. Hard tussock differs from silver tussock in its leaves feeling rough and its seed-head having short awns.

(c) BLUE TUSSOCK (*Poa Colensoi* and *Poa intermedia*) grow about 8 inches high with bluish, narrow leaves.

(d) BLUE WHEAT GRASS (*Agropyron scabrum*) grows up to 1 ft. 6 in. chiefly between silver tussock.

(e) SNOW GRASS (*Danthonia flavescens*). This is the tussock which grows at high altitude. Very tall, commonly 3 feet to 6 feet, it has broad leaves and feathery seed-heads.

The only palatable tussocks are, (1) the blue tussocks which are easily killed by continuous burning and by continuous close grazing and (2), the blue wheat grass which will stand hard grazing. In order to get palatable feed from tussocks many farmers used to burn them indiscriminately and then graze the young re-growth. Severe grazing with sheep combined with rabbits commonly resulted in death of the tussocks and hence the loss of much shelter for the plants which grew between them and which provided feed for sheep. Death of the other plants soon followed and soil protection being much reduced, allowed soil erosion to set in. To-day's problem on some of the high country is the restoration of the tussocks or of other plants similarly attuned to the hard climatic conditions ruling there.

17. SUCKLING CLOVER (*Trifolium dubium*).—Suckling clover is fairly distinctive with trailing stems, small leaflets with long terminal leaflet stalks and small yellow flower heads. This annual clover though rarely sown, is present in nearly all pastures. Although it yields a very scanty pasturage, its wide distribution on low-fertility soils, too poor for white clover and for subterranean clover, renders it one of the most important clovers. Frequently its presence is an indication of the advisability of topdressing. Having seed similar in size to that of white clover it is very often an impurity in white clover seed.

18. LOTUS HISPIDUS is similar in form to lotus major but is more hairy and has more florets in the head. It is a useful legume on very poor soils, mainly for early spring growth. Both as fodder and as green manure it has been of great value on clay soils of North Auckland.

D. GRASSES AND CLOVERS FOR SPECIAL SITUATIONS.

19. PRAIRIE GRASS (*Bromus catharticus*).—Somewhat similar in general appearance to cocksfoot it differs mainly in having hairy leaf sheaths. The paramount feature of prairie grass is its ability to produce forage from late autumn right through winter

till early spring. The herbage, while coarse-looking, is very palatable. Though not strictly a drought resister, it will withstand somewhat arid conditions. Restricted as a high producer to the warmer, high fertility areas of the Auckland Province and coastal Taranaki, it is used there mainly on town supply dairy farms. Under severe grazing in ordinary pasture, particularly with sheep, it soon disappears. However, in carefully controlled dairy pastures within its habitat range, it can be maintained and be useful. Probably best results will be obtained by assigning it to a special paddock which would serve as the winter complement to the summer paspalum paddock. Such a prairie grass paddock would be best fed off in breaks, but this is not altogether necessary provided it is not at any time grazed severely, and is given periodical spells.

20. MEADOW FOXTAIL (*Alopecurus pratensis*).—Distinguishing features of this grass are its purple basal leaf sheaths, rhizomes and hairs on the head. A perennial, which spreads by underground tillering, meadow foxtail ultimately makes a dense sward, often to the exclusion of other species. Its creeping habit is also advantageous in that it checks the invasion of weeds which occurs in open pastures. Because it is one of the hardiest forage plants known, spring frosts do it little or no harm, so it can produce, when well grown, a large yield of winter and early spring feed, and even when run to flower there is always a good bottom of leafy growth. As meadow foxtail is slow to develop from seed, it should be used only for permanent pastures in which it associates well with timothy. A valuable permanent pasture grass on highly fertile swampy country, it may be established usefully wherever the conditions are likely for a considerable period to remain too wet in the winter for ryegrass to thrive.

21. POA PRATENSIS.—With a canoe-shaped leaf blade and forming rhizomes, *Poa pratensis* is easily distinguishable. Being both a twitch and a perennial this grass when established is difficult to eradicate and so is not suitable for land that is likely to be cropped. It is suited only to loose soils under warm and fairly moist conditions. Moreover, as it is never a high-producing grass, it is useful mainly because of its twitchy habit in binding loose soils on hill country and on sandy country where it may prepare the ground for better grasses such as cocksfoot. The seed is imported mostly from America, where the grass is somewhat famous under the name of Kentucky Blue Grass.

22. Poa trivialis.—This grass is similar in appearance to *Poa pratensis* but has a much longer ligule and no rhizomes. A low producing grass, it nevertheless is one of the best bottom grasses for the stiffer and damper soils. Essentially a companion plant to meadow foxtail and timothy, it is useful in those pastures just too wet for permanent pasture of perennial ryegrass.

23. Phalaris tuberosa.—An erect-growing grass *Phalaris tuberosa* has two very distinctive external features:—a very long ligule and pink swellings at the base.

Due to its upright habit, its strong winter growth and its ability to resist drought very well, phalaris has a place in New Zealand farming, mainly in special purpose pasture. However, in a mixed sward on hill country with low rainfall, it has a place for keeping up summer production and for helping to check erosion. With its wide range of habitat it has its place in several localities throughout the country. Being rather slow in becoming established, phalaris must be sown in a weed-free seed-bed early in the autumn and grazed only lightly in its first year.

24. Marram Grass (*Ammophila arenaria*).—This is the best sand-binding grass in New Zealand. It is characterised by its large size, narrow leaves, thick rhizomes, long dense heads, and ability to grow up through accumulating sand. While usually not a farm grass, marram grass affects farming in that it is the best plant for use in the first stage of stabilising sand drifts which otherwise may migrate and cover good farming land. Such country occurs chiefly on the west coast of the North Island, but there are some sand drifts inland also. Marram being a twitch and tall-growing has the capacity to spread and bind the sand and also to grow well upwards as the sand rises.

After fixing the fore-dune with a strong brush fence two-year-old marram grass plants each with at least two rooted nodes are planted, during wet weather, about 8 inches deep in rows 2 feet to 3 feet apart. When stabilised, the sand can be surface sown with yellow lupins followed some time later with plantations of suitable trees such as Pinus radiata and Cupressus macrocarpa.

25. Spartina (*Spartina Townsendii*).—A short grass with short leaf blades it spreads laterally by the vigorous rhizomes and further afield by pieces of shoot carried by the tide. In habitat spartina is limited to loose, raw mud below sea high-tide level. This habit and habitat makes it very useful in reclaiming tidal mud flats from the sea. Planted in rows on mud flats Spartina

thrives under periodical submergence by sea water. By collecting mud and growing through the mud it raises the level of the land above high-tide level thus preparing the way for stable pastures. The best area of spartina in New Zealand is near Invercargill.

26. PAMPAS GRASS (*Cortaderia selloana*).—Growing in great clumps 9 feet to 15 feet high and up to 3 feet wide at the butt, pampas grass is likely to be confused only with the native toi-toi (*Arundo conspicua*). These two plants may be distinguished as follows: Toi-toi has leaf blades with prominent veins which continue into the leaf sheaths, whereas in pampas these veins are not prominent; in toi-toi the plume-like inflorescences have florets each with both male and female parts together, but in pampas the male and female parts are completely separate on different plants; toi-toi flowers in the spring, pampas in the autumn.

As pampas grows well only in highly fertile soils and requires cutting or grazing hard twice yearly to produce palatable feed, it has a very limited utility. Where cropping and haymaking are difficult, pampas can provide maintenance fodder for cattle during periods of pasture scarcity. As shelter for sheep it is useful especially after early shearing.

27. STRAWBERRY CLOVER (*Trifolium fragiferum*).—A perennial clover, strawberry clover is distinguished from white clover by its oval leaflets and its strawberry-like fruits. Being able to grow in soil too wet or too salty for white clover, strawberry clover is valuable on low-lying wet areas and on country subject to occasional inundation with sea water and on land being reclaimed from the sea.

One outstanding imported strain called Palestine Strawberry Clover makes good winter growth, a feature absent in the other strains of the species.

28. ALSIKE (*Trifolium hybridum*).—Alsike is not a hybrid as its name implies. Its outstanding feature for recognition is the large stipules which taper gradually to their tips. On fertile soils where it grows well its life is somewhat short, and usually after two or three years white clover gradually replaces it. On damp soils it associates well with meadow foxtail and timothy. Being able to withstand very cold conditions, notably in the seedling stage, it is very suited to high country in the South Island. For permanent pastures on fertile rather wet soils, on reclaimed tidal flats and at high altitudes alsike is a good substitute for red clover.

Herbs in Pasture. By a herb, in connexion with pasture, is meant a plant which may be of value in a pasture but which is not closely related to either grasses or clovers. Chicory, for example, is a plant which has been included in some permanent pastures. Yarrow, burnet and plantain, though regarded as weeds in most pastures, are useful in poor pastures. Being deep-rooted, herbs are able to obtain water and minerals from greater depths than can grasses and clovers. There may be some value in herbs in a pasture providing variety in the diet of the grazing animals. Possibly as a result the animals are healthier on pasture with herbs than on pasture without herbs.

PASTURE STRAINS AND CERTIFICATION

One of the most important scientific discoveries affecting farming is that which showed the significance of strain in plants. So far we have considered chiefly the common pasture plant species. A *species* may be broadly defined as a group of individuals which all have the same kind of external features and which breed true for these kinds of features when bred among themselves. Thus if individuals of the species called perennial ryegrass are inter-bred, all the offspring have the features by which we recognise perennial ryegrass. A species like perennial ryegrass, however, growing for many years under one set of environmental conditions develops by natural selection individuals with internal differences from other individuals of perennial ryegrass growing under a markedly different set of conditions. In other words different kinds of habitat produce different kinds of plants within a species, plants which generally look the same but in many ways act differently. A plant type (or variety or strain) of a species developed in response to a particular habitat is called an *ecotype*.

This scientific truth about ecotypes was first applied to pasture plants by Sir George Stapledon in Wales. In 1928 he reported several ecotypes in cocksfoot developed under different farming systems, e.g. a leafy type in old grazing pastures and a stemmy type in paddocks kept regularly and frequently for hay. Meanwhile in New Zealand Dr. Hilgendorf had shown there was much variation in ryegrass and cocksfoot from different places in the South Island. Sir Bruce Levy too had directed attention to the variation in the chief pasture species.

Until about the year 1930 New Zealand pasture seeds had been sold largely on the basis of germination, purity and appearance, little regard being paid to the origin of the seed. (See Chapter 2.)

Some farmers knew that persistent ryegrass came from Hawkes Bay and persistent cocksfoot from Akaroa, but 'only about 30 per cent of all ryegrass seed on the market prior to 1929 was of the true perennial type' and a large proportion of the cocksfoot was of a short-lived stemmy type from Denmark. New Zealand farmers could not rely upon their most productive grass, perennial ryegrass, living up to its name, for often it almost completely died out within three years or so of sowing. If the farm was ploughable, recultivating and resowing every three years to replenish the ryegrass was necessary and this was expensive; if unploughable, species like browntop and danthonia took over and production dropped considerably. In some cases the position was much worse than this. On some unploughable country out of bush, with the failure of perennial ryegrass and of other important plants too, such as white clover and cocksfoot, the fewer stock that could be carried were unable to prevent the secondary growth of weeds taking possession. As a result many farmers had to abandon their farms. Other factors of course such as lack of topdressing contributed to the result.

Agricultural scientists, notably A. H. Cockayne, Levy and W. Davies tackled the problem, and in 1929 Levy and Davies published the results of their investigations into ryegrass. Several ecotypes were shown to exist in New Zealand. From Canterbury, where pastures were short-lived, the ecotype was short-lived; from Hawkes Bay, Poverty Bay and Sandon, where seed was harvested from long-lived pastures, the ecotype was long-lived. Immediately there was a great demand for these and other persistent ecotypes, and, as they had developed in regions favouring persistency they were called *regional strains,* notably Hawkes Bay and Poverty Bay ryegrass, Hawkes Bay and Rangiora white clover and Akaroa cocksfoot.

Because the seeds of different strains of a species all look similar, it was necessary to be able to distinguish between them. It was also necessary that the identity of superior strains be maintained and that farmers get what they need. So a certification scheme for pasture seeds was designed and introduced in 1929 by J. W. Hadfield.

Exercise 2.—In plots of strains of pasture plants (see Chapter 7) make observations and comparisons of the strains within each species for such features as leafiness, winter growth, resistance to disease, resistance to drought. Temporarily confine sheep on the plots and observe relative palatability and recovery after grazing.

MASS SELECTION

Besides ryegrass the chief pasture species subject to selection were:—white clover, red clover and cocksfoot. Thousands of samples of each species of seed from different places (*lines of seed*) from all over New Zealand and from other temperate zone countries were sown and the seedlings planted out individually in rows. Frequent and regular observations of the individual plants were made for the *features of strains* such as persistency, leafiness, recovery after grazing, resistance to disease (e.g. rust), growth form, palatability, rapidity of development, seasonal growth, and time of flowering. By selecting plants possessing these features, multiplying them by clonal division and saving the seed, superior strains were produced and certified. This selection from a great mass of plant material is called mass selection. It takes a long time, by this method of selection, to isolate superior strains and the amount of improvement is usually small.

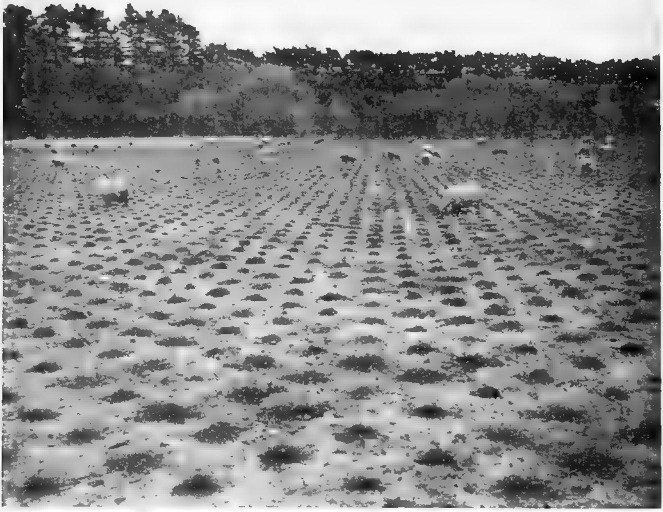


FIG. 84. Single plants of ryegrass progenies under test
(*Grasslands Division, D.S.I.R.*)

Breeding Improved Strains

Under controlled conditions a *strain* may be defined as a group of externally alike individuals in a species which differ from other strains within that species in one or more features such as leafiness, palatability and persistency. It must be realised that the individuals within a strain show some variation among themselves but the great majority of them agree in having the strain features for which they were selected and bred.

In order to produce still better strains breeding is carried out. This was discussed in Chapter 7. Briefly, breeding of pasture plants means that the best pairs of plants in the current strains are selected, and, so as to control pollination, isolated from other plants of the same or related species. After inter-pollination of these plant pairs in isolation the resulting seed from each pair of plants is sown. The seedling progeny from each parental pair are space planted in a paddock, observed and compared with the ideal the breeder has in mind.

By this *progeny testing,* parents producing superior progeny are retained for seed and multiplication, the inferior parents being discarded. Hybridisation, that is the crossing of markedly different strains or of related species, is a means of still further improving pasture plants. Thus by crossing Italian ryegrass and perennial ryegrass Dr. Corkill, at the Grasslands Division produced short rotation ryegrass which has the quick establishing power, good winter growth and palatability of its Italian parent and some of the persistency of perennial ryegrass since it lasts, with good management, for four years or more.

Strain Testing

Newly-bred strains are compared with the best of the current strains by growing them in plots, closely in rows, or in rows of spaced single plants. Control plots or rows of the current strains are placed at intervals for comparison. Such testing is done at several places throughout New Zealand.

Multiplication

From the few ounces of seed produced by a plant breeder, the first crop of nucleus pedigree seed is raised in glasshouses. The second increase occurs in paddocks isolated from other grass of the same or related species to prevent contamination and deterioration of the strain by foreign pollen. To allow for elimination of foreign plants from seed already in the soil and to permit roguing, i.e. the elimination of plants of poor quality, the seed is sown at widely spaced intervals in rows in the paddock. From these plants the seed harvested is called *Nucleus Stock Seed* which is passed from the research station to the Department of Agriculture for further increase under the certification scheme.

PASTURE SEED CERTIFICATION

Carried out by the New Zealand Department of Agriculture, seed certification is designed to achieve two main aims:—(1) To increase, under the best obtainable conditions of isolation, the seed bred at the research station. (2) To enable seed buyers, who can seldom see the plants from which the seed was harvested, to get the kind of seed they want.

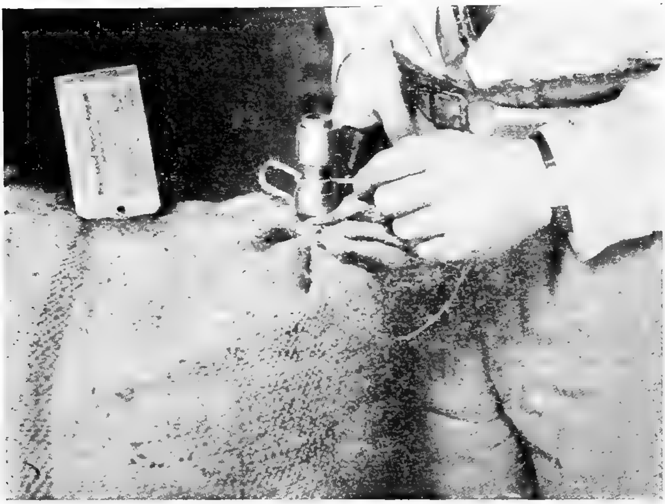


FIG. 85. Sealing machine-dressed seed
(From *Grasslands of New Zealand*, by Sir E. Bruce Levy)

While the details of certification vary a little according to the species concerned, the following main points in procedure apply generally:—Nucleus Stock Seed is sown on contract to the Department of Agriculture by farmers selected for their experience in seed production and for the suitability of their farms in regard to isolation conditions and freedom from weeds. After registering a farmer's paddock, giving it a number, and confirming the origin of the seed sown, the type or strain of the plants growing there is checked by a paddock inspection at the appropriate stage of growth. During the harvesting of the seed on the paddock the sacks of seed are branded and temporarily sealed. Supervision of the seed is continued when it is being cleaned, the sacks of cleaned seed being labelled and finally sealed. (See Fig. 85.)

Samples are taken from every sack of each line of seed and sent to the Seed Testing Station for germination and purity tests. Also, according to the type of seed, the samples are submitted to strain testing either in laboratory or plots.

As the seed becomes multiplied, it may, in spite of precautions of isolation, become outcrossed, and so it is graded down in the certification scales. The produce of Nucleus Stock Seed becomes, if it satisfies standards of field inspection, germination and purity, *Government Stock Seed* which is distributed to a greater number of farmers who are still carefully selected as before. In turn, the produce of Certified Government Stock Seed satisfying the required standards becomes *Certified Pedigree Seed* which is sold to all farmers, usually seed producers, who wish to buy it. The produce of Certified Pedigree Seed, if satisfactory, becomes *Certified Mother Seed* which is the highest grade available for export and which is commonly sown for grazing pastures. The plants grown from Certified Mother Seed are not subject to field inspection. If it is perennial ryegrass, a seed sample is tested by the ultraviolet ray test. Similarly white clover seed is tested by the picric acid test. An outline of these tests is given later. As before, if the appropriate tests are satisfactory, the seed is certified, this time in the lowest grade as *Certified Permanent Pasture Seed*. Where, however, the strain belongs to a species which has no definite qualifications for permanency, its lowest grade name is *Certified Standard Seed*.

At present the following pasture plants are included in the certification scheme:— perennial ryegrass, short rotation ryegrass, Italian ryegrass, white clover, red clover (broad red and Montgomery red), timothy, cocksfoot, subterranean clover (Mt. Barker and Tallarook), Phalaris tuberosa, and browntop.

THE ULTRA-VIOLET RAY TEST FOR RYEGRASS

Seeds of ryegrass are germinated on filter paper and after six days the filter paper with the seedlings is placed under ultraviolet light. If the seed is Italian ryegrass, its roots in contact with the filter paper will show a glow or fluorescence, and if perennial there will be no fluorescence. Hybrids between the two species will show varying amounts of fluorescence. Seed showing more than 4 per cent fluorescence cannot be certified as perennial.

THE PICRIC ACID TEST FOR WHITE CLOVER

On the eighth day after setting seed of white clover for germination the seedlings are put in test-tubes and each lot killed with three drops of toluene, or chloroform. Placing a strip of picric acid paper in each tube the stoppered tubes are incubated at 30° C. for three days. The colour change of the picric acid paper to a shade between bright yellow and orange is compared with standard colours. The darker the colour the better the strain.

Exercise 3.—(a) If you can borrow an ultra-violet ray lamp, test samples of ryegrass for fluorescence as above, taking say Italian, certified perennial, short rotation, and uncertified ryegrass seeds.

(b) Taking various samples of white clover seed, certified and uncertified, test them with picric acid paper as above. For the preparation of picric acid solution see the appendix.

SEED MIXTURES AND TYPES OF PASTURE

While considering earlier in the chapter the various species of pasture plants, there has been a good deal of discussion about types of pasture. In this section the types of pasture in relation to seed mixtures is dealt with. Reference should be made to the earlier sections for reasons why a species or a strain is included in a certain mixture.

It is useful to be able to recognise pasture seeds.

Exercise 4.—Examine, with the help of a hand lens, fresh seeds of the chief pasture species observing their size, colour, and shape. Make out a table with columns headed: name, size, colour, shape, number of seeds per lb. (For the last feature see the table at the end of this chapter.) Later, from a mixture of these seeds, separate the kinds and name them.

The main object of seed mixtures is to extend the seasonal range of pasture production so that there is good growth throughout the year. If this object could be achieved, there would be little need for conserving pasture as hay and silage in times of pasture abundance for use in times of pasture scarcity. However, until a farmer is sure he can successfully grow and use pasture straight from the paddock all the year round, he must continue to make hay and silage and perhaps also to use crops such as turnips for stock feed during periods of poor pasture production.

There are three methods of attempting to achieve the main objective of seed mixtures:—(a) By using a single, complex mixture over the whole farm, or (b) by having several simple mixtures, each on a separate block of paddocks, or (c) a combination of both methods (a) and (b). Which method should be used depends upon the farming conditions and upon the judgment and skill of the farmer. In a pasture there are many interacting factors of climate, soil, and grazing animal, some of which the farmer can control, others being outside his control. One factor, however, is clearly and directly within his control and that is the quality of the seed he uses in his seed mixtures. It must be emphasised that the best certified strains available should be used and that there be a good understanding of their characteristics and potentialities and of the management they need.

The main advantage in the use of mixtures of several species is that the species sort themselves out in their particular environments. This applies especially to hill country with its ridges and hollows where there is great variation of the environment particularly with regard to water supply, warmth and shade. Grazing, as a special feature of the environment, has a marked effect upon pastures sown with complex mixtures. Thus, for example, where species like short rotation ryegrass and red clover have been sown, the grazing must be carefully controlled if these species are to remain in the sward. However, even where soil conditions and management are fairly uniform, pasture sown with several species tends to become reduced after a few years to two or three species.

Commonly, under high fertility conditions with close, continuous grazing, perennial ryegrass and white clover tend to dominate. Still under high fertility and with lax and rotational grazing, short rotation ryegrass and red clover remain with the perennial ryegrass and white clover for at least a further few years. Under low fertility conditions and close and continuous grazing browntop and danthonia, alone of the large number of species sown, become dominant and almost the only species in the sward. (See the next chapter.)

The following mixtures are among those recommended by Sir Bruce Levy in *Grasslands of New Zealand,* and by Mr. S. H. Saxby in *Pasture Production in New Zealand.*

PERMANENT HIGH-PRODUCING PASTURES

A complex mixture for permanent high-producing pastures is prescribed for use over wide areas of both North and South Islands as follows:—

Certified	Perennial ryegrass	15 lb.
,,	Short-rotation ryegrass	10 lb.
,,	Cocksfoot	5 lb.
,,	Timothy	3 lb.
,,	Montgomery red clover	3 lb.
,,	White clover	2 lb.
,,	Crested dogstail	2 lb.
	Total per acre	40 lb.

A smaller amount of ryegrass is advisable when the summer rainfall is below that needed for good results with ryegrass, as under Canterbury and similar conditions, and again when it would not be economical to raise the fertility of land up to ryegrass standard by topdressing. In such case the cocksfoot should be increased to 10 lb.

This mixture is recommended for use on country with a carrying capacity which is, or can economically be made, at the rate of 1 cow to 2 or 3 acres or better; or at the rate of 2 to 3 ewes to the acre or better.

The above mixture, if used on land of the higher carrying capacity mentioned would result in a permanent pasture in which ryegrass and white clover would be dominant. If used on land of the lower carrying capacity it would tend to result in a pasture in which cocksfoot, dogstail, and white clover would be dominant unless, when soil moisture supply was favourable, it proved profitable to topdress to bring fertility up to the standard of ryegrass-white clover dominance.

Under certain special conditions the above mixture may with advantage be modified. The following instances of this are given because of their importance:—

On land of naturally high fertility, where the permanence and good growth of ryegrass all the year round are assured, cocksfoot may be omitted. There is only a very limited area of such land. When the cocksfoot is omitted the amount of ryegrass may be increased advantageously to 40 lb., (20 lb. certified perennial and 20 lb. short rotation ryegrass) and the other species of grass omitted.

For slightly wetter soils the timothy rate may be increased to 3 lb. and the crested dogstail omitted.

Meadow foxtail is a grass of high value on fertile swamps too wet in winter for success with ryegrass, and 6 lb. an acre may be included for such conditions. But if it is at all possible to drain such land and make it suitable for ryegrass this should be done, and ryegrass sown in preference to meadow foxtail.

In many northern districts of the North Island *Paspalum dilatatum* at the rate of 6 to 8 lb. an acre may advantageously replace cocksfoot.

Strawberry clover at the rate of 1 lb. to the acre may be added for salty marshy conditions, or it may be substituted for white clover on land too wet for the latter.

TEMPORARY PASTURES

Of one to two years' duration, temporary pastures are of considerable value, mainly because they can be sown—

(a) to yield green feed in winter or early spring;

(b) to spell and build up the fertility of land which has been regularly under the plough;

(c) to clear land of weeds such as blackberry, prior to the sowing of a permanent pasture.

As quick establishment and high productivity are required, mixtures for temporary pastures are of necessity simple. There are few species that satisfy the requirements and other species would be shaded out.

A popular suitable seed mixture for temporary pasture consists of

Certified Italian ryegrass or Short-rotation ryegrass - -	25 lb.
Certified Broad Red Clover -	4 lb.
Total per acre -	29 lb.

SHORT-ROTATION PASTURES

For what are called short-rotation pastures a somewhat different mixture has been found advisable. A short-rotation pasture is intended to have a life of four to eight years. Such pastures serve a useful purpose mainly on those farms on which, principally because of climatic conditions, cereals and other arable crops as well as pastures are the main consideration. On such farms short-rotation pastures give the land a beneficial rest, produce heavily during their short life, and fit in well with management requirements. This is called *ley farming* in which the land, having been cropped for a few years, is sown in short-rotation pasture to restore soil fertility.

In special cases they may be well justified under conditions which ordinarily call for the use of a permanent pasture mixture. For instance if land is known to be incompletely cleared of tall fescue infestation it is usually good practice to sow it down on a short-rotation pasture rather than a permanent pasture. The short-rotation pasture may be ploughed down when the secondary invasion of fescue becomes serious enough to justify this course, and eventually the land, when cleaned of the fescue, may be sown in permanent pasture.

A suitable seed mixture for the establishment of short-rotation pastures and special purpose winter and summer pastures consists of:—

Certified	short-rotation ryegrass	15 lb.
,,	perennial ryegrass -	10 lb.
,,	Montgomery red clover or ,, broad red clover -	3 lb.
,,	white clover - -	3 lb.
	Total per acre - -	31 lb.

SECONDARY BURN MIXTURE—

Certified	perennial ryegrass -	8 lb.
,,	browntop -	2 lb.
Dogstail	- -	4 lb.
Certified	white clover	1 lb.
Lotus uliginosus	- -	1 lb.
Danthonia pilosa	- -	3 lb.
	Total per acre - - -	19 lb.

This mixture is suitable for typical bracken, hard fern, and manuka burns. Where fertility is higher as on mahoe, wineberry, and fuchsia burns and 'logging up' burns, the addition of 4 to 6 lb. of cocksfoot to the mixture is quite justified.

On secondary burns ryegrass is included primarily to attract stock during the first six to nine months. It is doubful whether the expense of the true perennial ryegrass is justified on the harder, poorer country, but if ryegrass is expected to be permanent, and especially if topdressing is to be practised, then true perennial ryegrass should be used.

Under dry conditions such as obtain on much of the typical East Coast country substitute 3 lb. subterranean for the *Lotus uliginosus* and reduce the browntop to 1 lb.

It is better not to sow secondary burns before the autumn rains definitely can be expected—generally for the North Island this is about the middle of March. Hence in burning secondary growth it is well to make the main burning as late as possible—at the end of February or the beginning of March.

MIXTURE FOR OVERSOWING UNPLOUGHABLE HILL COUNTRY PASTURES

Certified perennial ryegrass -	10 lb.
" subterranean clover - -	2 lb.
" white clover - -	2 lb.
Crested dogstail -	3 lb.
Lotus uliginosus	½ lb.
Total per acre - -	17½ lb.

The main aim in oversowing hill country pastures is to include clover in the sward so that the nitrogen status of the soil, through the activity of the clover nodule bacteria, is raised to allow better grass growth. Where there is a good strain of ryegrass already present to some extent in the sward then the grass seed may be omitted from the mixture. Usually phosphate topdressing is also necessary for improvement of the pasture. It is more economical to sow seeds and fertiliser together rather than separately, but, if ordinary superphosphate is used, the germination of the seed is impaired. Such injury may be avoided by using a reverted superphosphate such as serpentine superphosphate or basic superphosphate. (For further reference to oversowing see the next chapter.)

SPECIAL PURPOSE PASTURE

Consisting of only one or a few species, seed mixtures for special purpose pastures are designed for:—(a) Summer or winter growth, or both. (b) Seed production. Here the mixture consists of one certified grass species with either certified white clover or certified red clover. (c) Combating animal diseases.

For example a pasture of white clover alone is safe for sheep likely to contract facial eczema on mixed pasture in the autumn.

Only purpose (a) will be dealt with here in detail. Thus for winter production either a mixture of 70 lb. per acre of prairie grass and 6 lb. per acre of red clover or 10 lb. per acre of *Phalaris tuberosa* alone is sown. For summer and winter production combined, the mixture used is similar to that for short-rotation pasture.

For dry conditions the amount of short-rotation ryegrass should be reduced to 15 lb. and 6 lb. of cocksfoot added. For Auckland Province and coastal Taranaki and Gisborne, 8 lb. of paspalum instead of the cocksfoot may be included. During the establishment of the pasture it must be grazed carefully to allow good development of the clovers. This pasture should be rotationally grazed in winter and early spring and then spelled or leniently grazed in November and December. When the red clover has grown well and the short-rotation ryegrass seeded, grazing is resumed with dominant red and white clovers and the mature growth of ryegrass for the summer. A second spelling must be observed in the autumn to allow for good development of the short-rotation ryegrass ready for winter grazing. Where paspalum is included, the November-December spelling encourages the development of the paspalum and white clover for the summer.

ESTABLISHING PASTURES

Having decided upon a seed mixture for a pasture, it is then necessary to choose the season of sowing, prepare the land and sow the seed.

SEASON OF SOWING

Successful sowing of pastures is confined mainly to spring and autumn. In autumn sowing an effort should be made to avoid the occurrence of a considerable dry spell after the sowing of the seed, and, further, autumn sowing should not be done so late as to create danger of injury to the seedlings by frost. In spring sowing it should not be so early and therefore so cold as to check germination, nor so late that the seedlings do not have time to become safely established before the advent of dry warm weather.

In many cases autumn sowing will be found to be most suitable—this is particularly the case with heavy land on account of the great difficulty of making it ready for grass before the spring is too far advanced. Further, the temperature of the land is higher in autumn, and hence more favourable to germination. The danger involved in autumn sowing is that the growth may be delayed by dry conditions, so that the plants will not be sufficiently developed to withstand the winter cold—this danger is greatest in respect to the clovers which, when well established, can endure cold that would destroy them in the more immature stage.

In general, at elevations greater than about 1000 ft., the prevalence of early winter frosts makes it essential that sowing be done in the spring rather than in the autumn.

Preparing the Land for Sowing

Except in the case of hill country, when land is being put down to grass, care should be taken that the ground is well drained, for all operations of seeding, manuring, and cultivating will prove more or less futile if this point is neglected. Few crops require more careful preparation of the land than does the crop of permanent pasture. The requirements in the way of seed-bed may be summed up as fineness, firmness, and freedom from weeds. (See Chapter 15.)

The superiority of the pasture round the headlands and along the paths is generally noticeable, and should serve to emphasise the desirability of a well-consolidated soil. The necessity for fineness of soil must be obvious when we consider how small are many of the most valuable seeds that are employed. Fertilisers and lime, according to the condition of the soil, should be applied before or during the seed sowing. (See Chapter 13.)

Sowing the Seed

At the time of seeding, the soil must not be very damp—if it gathers clods on the implements or sticks to the boots it is probably over-damp. Rolling just before sowing is often desirable in order to ensure firmness of the seed-bed and even covering after sowing.

The seed may be scattered broadcast or drilled. In either case, to ensure thoroughly even distribution, which is highly desirable, it is sometimes advisable to sow half the quantity in one direction, and the other half crossing this at right angles. A very light harrowing adequately serves to cover the seed. Much imperfect germination is due to covering the seed too deeply; many of them will not germinate at more than half-an-inch deep. A brush harrow or a light iron harrow will serve. It should be followed by the roller to get the desirable degree of consolidation and of closeness between soil particles and seed.

Successful establishment of permanent pastures generally results when the pasture is not sown with a companion crop such as barley and wheat, and should a companion crop be grown its rate of seeding should generally be lower than that normally adopted. Short-duration pastures may often with advantage be sown down with oats or barley as companion crops. However, it should be remembered that with all classes of pastures the better the companion crop the poorer is the pasture likely to be. This is because the shade resulting from the companion crop is apt to be harmful rather than protective. The shading effect of cereals on young pastures is lessened if the cereal is grazed or utilised for ensilage or chaff, for then the pasture is subjected to the shading influence for a shorter period.

Exercise 5.—On a map of New Zealand showing the provinces or the land districts show the distribution of the chief types of pasture.

PARTICULARS OF SEEDS OF PASTURE PLANTS

GRASS SEED

Name of seed	No. of Seed per lb.	Germination Per Cent	Bushel Weight Lb.
Perennial Ryegrass	250,000	85	30*
Italian Ryegrass	230,000	85	20–22*
Cocksfoot	560,000	75	16–18
Crested Dogstail	880,000	80	33
Timothy	1,250,000	90	46
Meadow Foxtail	620,000	36	8
Chewings Fescue	525,000	86	28
Poa trivialis	2,900,000	65	26
Poa pratensis	2,400,000	50	–
Browntop	5,500,000	60	–
Danthonia pilosa	500,000	45	5
Danthonia semi-annularis	1,000,000	45	3½
Paspalum	454,000	30	20
Phalaris tuberosa	400,000	45	46
Prairie Grass	42,000	75	17
Yorkshire Fog (shelled)	1,250,000	85	40

* Commercially 1 bushel of Ryegrass is always taken as equal to 20 lb.

CLOVER SEED

Name of seed	No. of Seed per lb.	Germination Per Cent	Bushel Weight Lb.
Red Clover	240,000	90	65½
White Clover	670,000	90	66
Alsike ..	630,000	90	66
Suckling Clover	1,000,000	80	66
Lotus hispidus	930,000	75	66
Lotus uliginosus	900,000	80	66

READING

'Pasture Production in New Zealand', S. H. Saxby. *N.Z. Dept. Agriculture Bulletin* No. 250

Grasslands of New Zealand, Levy

N.Z. Journal of Agriculture, Feb. 1957, pp. 132, 135; Nov. 1954, p. 481; Nov. 1953, p. 415; July 1951, p. 29; Dec. 1948, p. 568; June 1948, p. 529; Aug. 1947, p. 507

Grassland Bulletins

Rural Education Bulletins, July 1947, May and June 1949, Nov. 1955, Aug. 1956

Canterbury Chamber of Commerce Bulletin, No. 301

D.S.I.R. Bulletin, No. 49

Pasture Plants and Pastures of New Zealand, Hilgendorf

FILMS

(The National Film Library)

'Carpet of Grass'

18

Pasture Management

ECOLOGY

IN pasture management, we are considering the control by man of a type of vegetation called pasture. Such vegetation is a collection of plants growing together which has, as a whole, a certain distinctiveness or individuality and which is referred to as a *plant community*. As pasture without animals is unusual, pasture management usually involves also an *animal community*. Grazing animals affect the pasture and pasture affects the grazing animals. The scientific study of the relationships of plants and animals with their surroundings, the study of plant and animal communities, is called *ecology*.

Plant communities of the largest type such as tropical rain-forest, New Zealand bush, pine-forest, scrub-land, grassland and swampland are called *plant formations*. Each plant formation has one or more dominant plants of characteristic life form. By a *dominant plant* is meant that plant in a community which gives the community its characteristic appearance and which may control its structure, e.g. beech in South Island bush, kauri in North Auckland bush, and snow grass in the grassland of the high country in the South Island. Units in a plant formation dominated by one or more particular species are called *plant associations*, e.g. tawa association in native bush and ryegrass-white clover association in good quality pasture.

Life never stands still. Over the years there is change, usually progressive, from one kind of vegetation to another. This is called *succession*. There may be succession from bare ground or bare rock as on land recently emerged from the sea after earthquakes, alluvial deposits following river flooding, wind-blown sand of wandering dunes, scree deposits from mountain shingle slips, scoria and pumice deposits from volcanic eruptions. On bare rock the first inhabitants may be lichens and algae followed by mosses which, by death of parts of their bodies becoming incorporated with rock fragments, produce the first soil. More mosses then grow with annual herbs and then perennial herbs succeeding them and producing deeper soil. Shrubs can now become established gradually followed by trees to make the usual *climax community,* forest which is stable in the sense of being in balance or in equilibrium with all the existing conditions of climate, soil and life.

All communities if left to themselves progress towards the climax community, one association and community growing in consequence of its predecessor. This is called *ecological development.* Man, however, is constantly stopping or modifying the development or throwing it back to some other stage. An example of the last-mentioned action is the situation on some highland tussock country in Otago where annual burning and continuous hard grazing by sheep and rabbits have caused the reversion of the land to scabweed and even to completely bare ground.

A major modification of ecological development by man in New Zealand has been the conversion of forest and scrub lands to pasture. Most pasture in New Zealand today represents an *arrested climax* due to the activities of farmers and farm animals. That pasture is only an arrested stage of development is clearly seen where farmers have neglected their properties or have had to abandon them, for there is a marked tendency under such conditions for the vegetation to show succession first to scrub and then, except in the driest regions, to forest.

Because pasture is kept stable by the activities of man and his animals, that is, by the living or biotic factor of the environment, it is also referred to as a *biotic climax.* Both farmers and pasture scientists must take special account of the biotic factor, especially the part played by grazing animals in determining the productivity, persistency and composition of pasture. The individual plants in a pasture community are all struggling for existence, competing with one another under the many and varied conditions of the habitat. A knowledge of the reaction of plants to their environment is essential to good pasture management. (See the previous chapter.) Grazing too hard and too often results in poor pasture production and useful species become weaker and may die. Too lenient grazing, on the other hand, causes the tall-growing and less palatable grasses to dominate and the clovers to be suppressed largely due to shading. Carefully controlled grazing is essential if a properly balanced sward of the most useful grasses and clovers is to be maintained. The biotic factor in the habitat of a pasture can be almost completely controlled by a farmer. To some extent also, as we have seen in Chapters 8 to 16, the soil factor can be controlled. It is this control of the habitat of pasture and livestock, this influence on the ecology of pasture and grazing animal community, which is called pasture management.

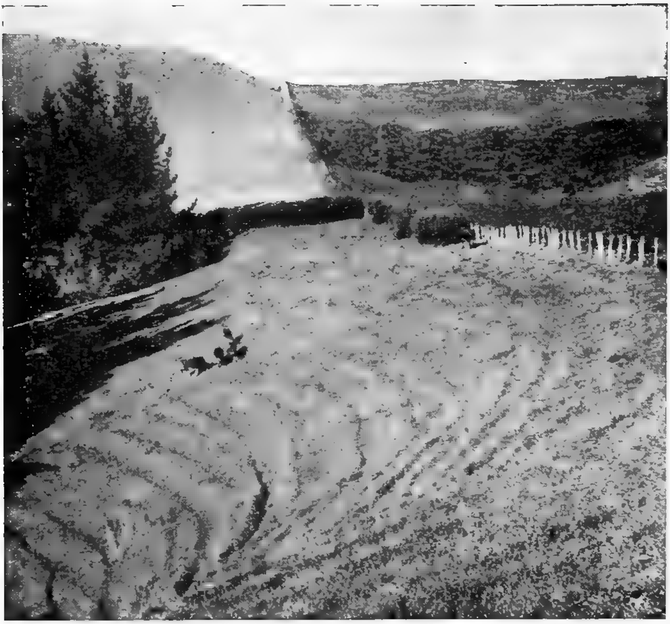


FIG. 86. *Foreground*: High-producing farm well sheltered, well managed and topdressed with phosphate and potash; *Top left-hand corner*: Poor farm, little fertiliser, poor management; *Right*: Farm covered in blackberry etc., no fertiliser, bad management (Uruti, North Taranaki)

(*N.Z. Journal of Agriculture*)

THE OBJECTIVE IN PASTURE MANAGEMENT

To be successful in his pasture management a farmer must clearly understand his objective. Such an objective will vary according to the pasture habitat which he is able economically to provide. To retain the most highly productive pasture, for example, he must have the highest possible soil fertility and the best possible control of the grazing. With normal grazing, never too close and never too lenient, a pasture on high fertility soil will show succession from the original delicate balance of species such as perennial ryegrass, short-rotation ryegrass, Montgomery red clover and white clover to a perennial ryegrass and white clover dominant pasture. If a farmer must allow for diminishing fertility following establishment of his pasture, he includes lower fertility-demanding species in his seed mixtures and manages his grazing to achieve succession to the pasture association aimed at, say, a cocksfoot-white clover dominant sward. On dry hill country which cannot be topdressed the objective would be a danthonia sward, and, on country with a high water-table in winter and early spring, a sward with meadow foxtail, timothy and white clover dominant.

Study of Pasture as a Plant Community

Exercise 1.—First of all practise recognising the common pasture species and revise the features of their habitats. If possible farm pastures should be studied. Failing access to these, small plots may be used.

(a) Compare the composition of the pastures in different kinds of places, e.g. normally grazed pasture, pasture commonly used for hay and silage, pasture rarely if ever grazed as in an uncultivated orchard or fenced-off area with a plantation of trees, pasture shut up for seed crops.

(b) Compare the composition of pasture within one paddock, e.g. normal area, near the gateway, near the water-trough, near a shade tree, in a hollow, on a rise, and, if the paddock is next a public road, near the roadway. Try to explain the differences.

(c) Make a line transect as follows:—On a country roadway stretch a line across the bordering pasture from the paved way to the fence. Record the plants touching the line and immediately under it and try to account for the variations.

(d) Compare the changes in the composition of a pasture during a year observing it say in February, April, July and October. If possible relate the changes to the weather and other apparent factors such as topdressing and grazing. As weather records may vary appreciably between places not far apart, it is desirable to keep the records for your own area. Suitable apparatus is:—a small Stevenson screen housing maximum and minimum thermometer, wet and dry bulb thermometers; also a rain gauge, anemometer, and thermometers at ground level and 6 ins. below ground level. These records are useful also in respect to facial eczema and irrigation. (See later in this chapter.)

(e) Select a uniform patch of lawn. Divide it into four equal parts and treat each part differently as follows:—(i) Mow closely once a week with removal of clippings. (ii) Mow closely once a week with return of clippings. (iii) Cut when 9 ins. high down to 2 ins. or 3 ins. high. (iv) Let go rank and cut only to remove flower heads. At intervals compare the species compositions of the four parts.

Note:—See also the exercises suggested later in this chapter.

In general, pasture management aims to secure the following results:—

(1) the greatest quantity of feed consistent with

(2) the quality of the feed;

(3) permanence or persistence of the sward;

(4) as far as possible a supply of feed which conforms with farm stock needs from season to season;

(5) feed at the most economical cost.

Good management comes from skilfully determining just how much effort should be directed to each of the five results that, taken together, form grass farming efficiency. If so much attention is given to any one that there is neglect of others then inefficiency is apt to rise at once. For instance, a farmer in striving for quality in the feed from his pastures, if not careful, may experience a falling-off in production which outweighs in value the gain in quality which brought about the falling-off in quantity, and conversely if attention is concentrated on quantity then an undesirable falling-off in quality is almost certain to take place. To sum up, good pasture management calls for skilful balancing of results in respect to five matters which interact, and which at times are mutually antagonistic in their claims. Hence it is not a simple or an easy art.

THE BEARING OF MILK PRODUCTION ON NEW ZEALAND FARMING

The detailed nature of the objective is determined primarily by the prominence of milk production in New Zealand farming. Milk production is the foundation of the major and the most valuable farming industries: directly in the case of butter, cheese, fat lamb, and pig production; indirectly in the case of mutton, wool and beef. From this it follows that an important requirement of the feed from pastures is that it be fitted for milk production.

To secure the production of such feed it is necessary to keep the pastures youthful: youthful in characteristics rather than in years. The essential characteristics are vigour, a long season of active production, and a leafy as distinct from a stemmy condition of growth which pastures possess when the flowering and seeding stages are reached.

THE VALUE OF LEAFY PASTURE

The comparative feeding values of leafy pasture growth and of the stemmy growth which characterises herbage at or about the stage of cutting for hay are as follows:—

1. The dry matter of samples from leafy pastures contains approximately twice as much phosphate and lime as is contained in dry matter from corresponding herbage at the hay stage.

2. The dry matter of leafy pasturage contains approximately two-and-a-half times as much protein as occurs at the hay stage.

3. About eighty per cent of the dry matter of leafy pasturage is digestible, whereas only from forty to fifty per cent of the dry matter in stemmy pasturage is digestible.

The significance of these three facts lies in the further fact that the rations of 'wet' stock such as cows or ewes in milk are apt to fall short of requirements in respect to their mineral content, their protein content, and their digestibility. And the more productive the stock the greater is the likelihood that the feed will fail to meet its needs. Milk contains not only protein but also lime and phosphates, all of which must be derived from corresponding substances in the pastures, and so the cow yielding four gallons of milk daily demands more of such substances in its ration than does the cow yielding two gallons daily, and, similarly, other circumstances being equal, the ewe mothering two lambs requires more of them than the ewe with one lamb. To sum up, the more intense the production the greater is the need for leafy pasturage with its greater digestibility, greater content of mineral matter (which is required mainly for milk and bone formation), and greater content of protein, which is required mainly for milk and flesh formation.

A second reason why it is generally advisable to maintain pastures in a leafy, relatively short condition lies in the fact that it prolongs the season of their growth. Pastures which are allowed to become tall and stemmy in summer appear to exhaust themselves in the development of flower heads, and certainly assume a resting condition during a considerable and critical portion of the producing season, i.e. during late summer and early autumn. On the other hand pastures which have not been allowed to develop flower heads tend to continue the production of leafy herbage right through the season.

A third reason for avoiding stemmy growth on pasture lies in the fact that swards which are allowed to become tall tend to become undesirably open, and certain valuable species may be weakened by taller-growing competitive constituents of the sward.

How to Attain the Objective.—The main measures calling for attention in the securing of the maximum amount of leafy pasture growth constitute a long but important list. They comprise:—

(1) Judicious constitution of pasture seed mixtures including the use of certified leafy strains. (See Chapter 17.)

(2) Topdressing with fertilisers and lime. (See Chapters 11 and 13.)

(3) Systematic controlled grazing with its subsidiaries such as farm subdivision, autumn saving of pasture and silage production.

(4) Pasture 'topping'.

(5) Pasture harrowing.

(6) Draining. (See Chapter 15.)

(7) Stock treading.

(8) Irrigation.

(9) Sod seeding.

This formidable list, which is far from exhaustive of the matters calling for attention, shows that high-grade pasture farming is not at all a simple matter.

MANAGEMENT OF NEWLY-SOWN PASTURES

In sowing a particular seed mixture the aims are to get a pasture which will be attuned to the habitat ruling in the area sown and which will be highly productive over as much of the year as possible. The kind of pasture actually produced will depend not only on the seed mixture and the fertility of the soil but also very largely on the grazing management of the new sward. Being a very delicately balanced plant association, a new pasture needs very careful grazing management. Otherwise succession will set in towards poor producing pasture. The first grazing must be carried out before the quicker developing and shorter lived species, such as short-rotation ryegrass, shade too much the slower developing and more permanent species such as white clover, and perhaps also before weeds exert their shading effects. This grazing must also be lenient to prevent very close defoliation and rooting out of the plants which have not had time to become firmly rooted. Excessive grazing would soon kill the shorter lived species such as short rotation ryegrass and red clover. The rule is to give newly sown pasture light grazing by a heavy concentration of stock, preferably sheep or young cattle, for a short time. This makes for even defoliation without selection, and ensures that the leaf area, the plant factory, is still sufficiently large to maintain and develop strong and deep roots.

Exercise 2.—Observe a newly sown pasture at regular intervals noting the composition. Do you notice succession from one association to another?

PASTURE TOPDRESSING

The greatest single factor that generally may be put into operation for the immediate substantial stimulation of production from pasture is topdressing with artificial fertilisers. This is chiefly because phosphorus stimulates the clovers to grow and produce nitrogen which becomes available to the grasses of the pasture. Phosphorus and nitrogen, being the two elements most commonly in short supply, thus together make a great impact on pasture growth. Hence normally the first step in any topdressing programme should be the application of a phosphatic fertiliser mainly to stimulate a good growth of clover. If there is no clover in the pasture, then one or more species such as certified white clover or certified subterranean clover should be sown at or about the same time. The fertiliser may need to include also one or more of the elements potassium, molybdenum and sulphur. Lime may also be necessary. (See Chapters 11 and 13.)

The most suitable season for the application of phosphatic manures to pasture varies with circumstances. As a rule the major consideration in phosphatic topdressing is the provision of growth for grazing as distinct from mowing, and when this is the case the even distribution of the production of pasture throughout the year should be the main aim. Hence the policy should be to apply phosphatic manure at such a season that its greatest possible influence is felt during periods of low production of pasture. In conformity with this policy, application of phosphates in late summer or autumn is popular, and is becoming increasingly favoured in preference to application in early spring. The more slowly-acting phosphates especially should be applied in the fall rather than in the spring. Superphosphate applied in the spring usually gives good results, but its maximum effect is felt in the early summer when there is generally abundant, if not excessive, growth of pastures. Some successful farmers carry out topdressing with phosphates at two or more seasons, such as spring and autumn, and a limited amount of investigational work suggests that, as a rule, the practice of these farmers is sound.

The amount of phosphatic fertiliser that may be most profitably applied varies greatly with such circumstances as the natural fertility of the land, the price of farm products and the management of the pasture growth. Over extensive areas, particularly where the annual rainfall exceeds 30 to 35 inches, annual applications of 3 cwt. an acre have been found decidedly profitable on land of fair to good quality. Even when the rainfall is good it may be unprofitable to apply phosphatic manure to markedly inferior land, e.g. some hill-country sheep farms.

There are not many pasture areas in New Zealand where *potassium* is inherently lacking, but there are wide areas where induced deficiencies of potassium have developed. This is mainly where phosphate has been applied for many years because phosphorus was the limiting factor to pasture growth but where now potassium is the limiting factor. As much of the potassium in pasture eaten by a grazing animal is returned to the soil in the urine, soil deficiency of potassium need not be induced if the grazing is uniform. If, however, on a dairy farm those paddocks near the milking shed are used exclusively for night grazing, deficiency of potassium is likely to develop in the day paddocks. This is because dairy cows eat more in the daytime than at night, very little after midnight, and go back to the day paddocks almost empty after the morning milking. Thus the night paddocks gain at the expense of the day paddocks. This of course applies to the other fertilising elements in the dung and urine besides potassium. Similarly, if certain paddocks on a farm are continually shut up for hay and silage and the produce fed out on other paddocks, the shut-up paddocks will develop potassium deficiency, and possibly deficiencies of other elements too.

Except where potassium is very deficient ready-made mixtures of phosphate and potassic fertilisers such as potassic serpentine superphosphate are suitable. Usually on potassium deficient soils ½ to 1 cwt. of potassic fertiliser per acre is sufficient.

As was explained in Chapter 11 there is little need in New Zealand for topdressing with *nitrogen*. Where pasture seed mixtures are sown on poor soil which has had little or no good clover in its previous plant cover, the application of nitrogenous fertilisers is necessary for good establishment of the pasture. Sulphate of ammonia and similar nitrogenous manures applied at the rate of 1 to 2 cwt. an acre in April or May will generally give a substantial increase in the amount of winter feed available from pastures, and applied in July will similarly increase the spring growth of pastures. This applies only if the pasture is growing. Dormant plants will not be stimulated into growth during cold weather. Whether the use of nitrogenous manures at the times mentioned will prove profitable depends on several circumstances, chief of which probably is the amount of winter to early spring feed provision for nitrogenous manures.

Liming of pasture has produced very diverse results in New Zealand making it impossible to give any general rule about liming. However, where the lime status of the soil is low and lime is cheap and readily available, then liming of pasture is likely to be profitable. This applies more to easy contour country where bulk spreading of the lime is possible than to hill country where spreading has to be done by aeroplane, blower or hand.

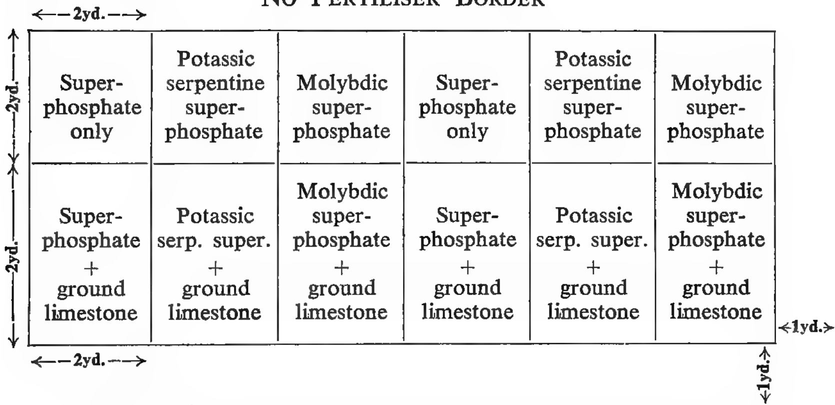
Usually the main visible effect of lime on pasture is the increased vigour of the clover.

When the response to phosphates is poor, liming is always worth a trial unless there is some other obvious weak link in the chain of factors giving fertility.

A PASTURE TOPDRESSING TRIAL

Exercise 3.—Carefully choose the site for a pasture topdressing trial by selecting an area with apparent uniformity of pasture composition, soil type and lie of the land; place it well away from gateways, trees, fences and other fixed objects. Then fix one corner of the chosen area by measurements to two widely separated fixed objects, e.g. strainer post. Lay out the plots, getting the right angles correctly, and topdress them according to some such scheme as that given in the diagram below.

NO FERTILISER BORDER



Super-phosphate only	Potassic serpentine super-phosphate	Molybdic super-phosphate	Super-phosphate only	Potassic serpentine super-phosphate	Molybdic super-phosphate
Super-phosphate + ground limestone	Potassic serp. super. + ground limestone	Molybdic super-phosphate + ground limestone	Super-phosphate + ground limestone	Potassic serp. super. + ground limestone	Molybdic super-phosphate + ground limestone

Determine the pasture composition of the plots soon after they have been marked out and at regular intervals thereafter by a method of pasture analysis such as the point analysis method.

PASTURE POINT ANALYSIS

In order to get a fairly accurate measure of pasture composition, samples of the herbage are noted with the help of an instrument such as a pasture point analyser. This consists of a two-peg frame holding ten long pins parallel to one another in a straight line, each pin being placed about 1 in. from the next one. Pegging the analyser vertically into a place selected at random in a plot, note is made of every plant pierced or touched by every pin. This is repeated in three or four more places selected at random and widely distributed over the plot. The total 'strikes' of each species on that plot is then found by addition to give an assessment of the relative abundance of every species on the plot. By treating all the plots and the border similarly at regular intervals, changes in pasture composition can be observed, and, by comparing the assessed compositions of the various plots and of the border kept without fertiliser, the effects of the fertilisers can be estimated.

GRAZING MANAGEMENT OF PASTURES

The method of grazing or utilising pastures is such a weighty factor in determining their yields that it ranks in importance with such recognised important factors as the soil and climatic conditions. Indeed, experience in New Zealand would make it seem difficult to emphasise unduly the attention that should be devoted to the proper grazing management of pastures. It is a waste to apply fertilisers if the extra pasture produced is not fully used and if the pasture is injured by faulty grazing at wrong times. A golden rule for grazing management is, as far as possible, to give a pasture a rest from grazing when it is beginning to make new growth and to graze it fully but not too heavily when it is growing well. The longer the intervals between successive grazings, up to a maximum when shading of valuable components of the sward starts to be too great, the greater the production from the pasture. All this means *controlled grazing*, that is, the management of the grazing of a sward so that every useful species is allowed sufficient light and sufficient leaf area at all times, and so is able to give its maximum production when most required.

MEANS OF SECURING CONTROLLED GRAZING

One of the most important of these practices is appropriate manipulation of the stock in grazing. It is often advisable to adopt what is termed intensive as distinct from extensive grazing. The essential difference between these forms of grazing is readily indicated by specific instances. Extensive grazing, for instance, would be in operation if a herd of 45 cows were allowed to browse over a considerable portion of a farm at the one time. In intensive grazing, on the other hand, instead of 45 cows being allowed to browse over a whole farm of eight to ten or more paddocks, they would be concentrated into one paddock for a sufficiently long period to have the growth reduced to such an extent that to keep

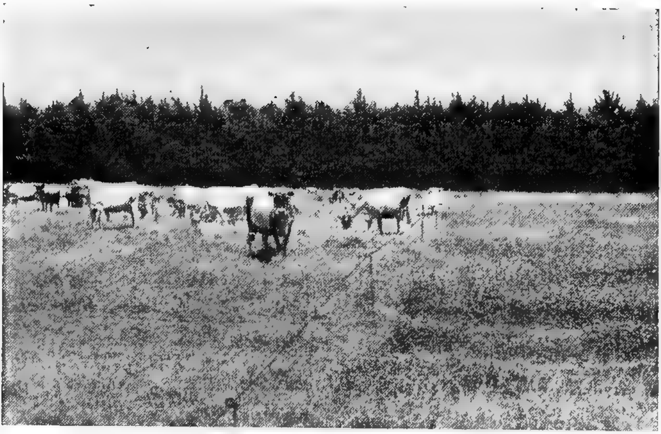


FIG. 87. Controlled grazing. Dairy herd at Flock House under rationed grazing with the aid of an electric fence
(*N.Z. Journal of Agriculture*)

the stock longer in that paddock would mean that they would suffer. When this is the position, the stock would be transferred to another paddock which calls for similar treatment, and then in due course, in a similar way, to other paddocks until all available paddocks have been grazed over or until the growth in the paddock first grazed, under this system, has reached the stage when again it can be most advantageously grazed. At this stage another cycle of grazing over the paddocks in turn should be commenced. *Such a system of grazing is called 'rotational' grazing.* If the rate of growth becomes so great that to graze all the paddocks would mean that some of them would become too rank for most advantageous grazing, then a paddock or paddocks providing growth in excess of the grazing requirements should be dropped from the series of paddocks on which rotational grazing is being practised. The paddocks so dropped from the rotational grazing series should be shut up for hay or for silage production, but even if it is not possible to utilise them in this way it is frequently advisable to drop them from the grazing programme so that those being grazed may be kept properly controlled. If dry stock are available they are used to follow up the first grazing to complete the defoliation evenly.

There are vital differences between proper rotational grazing and merely shifting the stock about. Many farmers frequently and regularly shift their stock from one paddock to another, and so in one sense they graze in rotation, but they do not practise rotational grazing as just described because —

(1) They fail to eat down the growth thoroughly and evenly before transferring the stock to another field.

(2) They fail frequently to commence grazing after a period of spelling, when the pasture growth is at the right stage to be grazed again with best results. Generally this occurs because they endeavour to retain too many paddocks in their cycle of grazing, with the result that the growth on the field at the beginning of the cycle becomes too rank and mature before the stock are returned to it. The general result is that rank-growing grasses and weeds tend to become dominant at the expense of the clovers and the more useful grasses. Consequently production of nutritive pasture becomes low and livestock production falls.

The essential features of systems of rotation grazing which have given good results in New Zealand are—

(1) Grazing of fields in spring and summer in such a way that, while they do not become rank and tufty, they are not subjected to really hard grazing.

(2) Such grazing is secured by a system of alternate grazing and spelling of fields in which the grazing periods commonly are of one to three days' duration, and the periods of spelling of from six to eight days' duration during the season of rapid growth of pastures and somewhat longer at other seasons.

(3) Under thorough, though not especially close farm subdivision, good results have been obtained in dairying on farms consisting of from ten to sixteen paddocks.

(4) The employment of ensilage, 'topping', and grass harrowing as valuable auxiliaries in ways described later.

RATIONED GRAZING

Also called strip grazing, break feeding, and close folding, rationed grazing is a still more intensive method of achieving controlled grazing. Existing paddocks are temporarily subdivided into sections or strips allowing the livestock to graze in relatively large numbers on a small area at a time. The subdivision is usually done with an electric fence, one wire 2 ft. 6 ins. above the ground being required for dairy cows, and three wires, at intervals from the ground of 8 ins., 16 ins., and 26 ins. respectively, for sheep.

It is most commonly used with dairy cows and on some farms it is used all the year round. The best procedure is to use rectangular strips with a fence behind as well as in front of the cows, sometimes called the 'fore-and-aft' method. (See the figure below.)

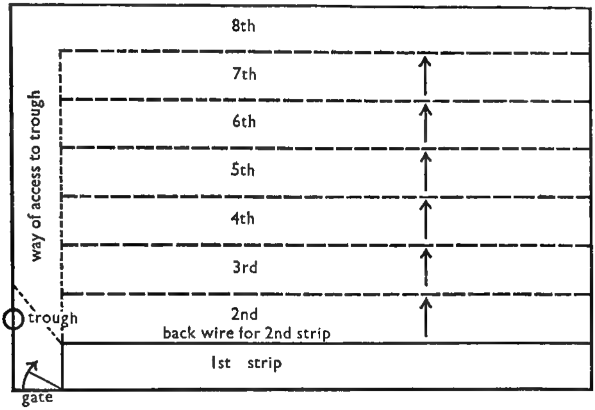


FIG. 88. Divisions of a paddock during rationed grazing

Shifting the electric fence takes 15 to 30 mins. and folds off the half-day's ration. During periods of good pasture growth and with good pasture, this ration would be about an acre for 100 cows. When the paddock has been fed off, dry stock are turned in, or the mower used, to clean up any roughage. The paddock is then harrowed and shut up for a period varying from 3 weeks to 3 months according to the season.

Advantages of rationed grazing over rotational grazing appear to be:—

(1) The daily amount eaten being rationed both under-feeding and over-feeding of the livestock are avoided.

(2) Rationing also conserves pasture in times of scarcity such as early spring and late summer, the bulk of the daily intake of food being made up with hay and silage.

(3) Because fouling of the herbage not eaten is at a minimum, there is less wastage.

(4) There is a better distribution of dung and urine making subsequent growth more even and so keeping an even distribution of desirable species.

(5) Selective grazing of the more palatable species is avoided, the whole pasture tending to be eaten and the less valuable species kept under control.

(6) Bloat disease and perhaps other diseases may be better controlled.

One drawback of the system is that special provision must be made for watering the stock. If a movable trough is not used, access to the paddock trough must be provided. (See the diagram.)

AUTUMN-SAVING OF PASTURES

Early in the autumn when the supply of pasture feed is usually greater than the demand from stock, it is good practice to conserve some of this surplus feed *in situ* by shutting up a portion of the farm either all at once or with paddocks in sequence up to mid-winter. Selection of the best available pastures is advisable, preferably those dominantly ryegrass and white clover. Ryegrass, especially short rotation ryegrass, is desirable because it grows in the winter, and white clover because it will have built up a good store of available soil nitrogen for the winter grass growth. The selected pastures should be topdressed with fertiliser early in the autumn and should be well drained and well sheltered. In order to get good growth before the winter, early shutting up is necessary, and, to this end, the feeding out of hay and silage should be started well before the need for supplementary feed is apparent.

EFFECTS OF GRAZING ANIMALS

Up to this stage we have understood that animals in getting their food from pasture defoliate the plants, and that for good production of pasture food this defoliation must be controlled. A second effect of the grazing animal we have discussed is its return of substances to the soil. Much of the material eaten is returned to the pasture in the droppings and, if evenly distributed, promotes the fertility of the soil. It has been shown at the Grasslands Division, Palmerston North, that sheep grazing good pasture on fertile soil return annually to the soil in their dung and urine fertilising substances equivalent per acre to 1 ton of sulphate of ammonia, ½ ton of chloride of potassium, and 8 cwt. of superphosphate together with other elements in 10 tons of dung. Thus under a temperate climate with ample rainfall high-yielding pastures make possible heavy stocking which promotes high soil fertility which produces, to complete a cycle, high-yielding pastures of the order of 14,000 lb. of dry matter per acre per annum. This may be called the cycle of fertility in pasture management.

A third major effect of grazing animals on pasture is the *treading by grazing animals.* This treading is shown in four important directions:—(1) *In soil compaction.* This is usually useful on light soils, such as coarse, pumice soils, to improve the soil water-holding capacity. On heavy soils in wet weather, however, soil compaction is undesirable because the soil structure is broken down, or 'pugged', reducing water penetration and aeration. Farmers on such soils commonly spell these pastures in the winter by having a run-off for the stock on higher ground, or carry out such a practice as the heavy feeding of such forages as hay, ensilage, and roots on a very restricted portion of the farm, so that damage to the remainder by 'poaching' may be avoided.

(2) Trampling has a direct effect on pasture plants. It is useful in crushing weeds such as bracken fern and in securing succession to high-producing pasture of species which withstand a good deal of trampling, notably perennial ryegrass and white clover. Too much trampling, as in gateways and on stock tracks, results in the death of plants. That is why on a dairy farm a paved central race reduces loss of pasture by trampling.

(3) Excessive trampling on an extensive scale produces bare spaces in pasture letting in the light to the soil and so allowing weeds to become established. To restore good pasture and to prevent such ingress of weeds sod-seeding may be helpful. (See a later section.)

(4) Where trampling displaces turves in wet weather the pasture can be restored by light rolling while the soil is soft. Dung is spread at the same time. To allow the broken surface to heal following this treatment, the pasture is left ungrazed for three weeks or more. Thus the turves become re-rooted and weeds cannot become established.

TOPPING OF PASTURES

It may be that the growth of the pastures is found to be somewhat in excess of the grazing requirements of the stock, and yet it is felt that no paddock may be dropped safely out of the grazing programme without submitting to the risk of being somewhat short of feed. A remedy for this position usually lies in further subdivision—often half a field could be dropped without risk, when a whole paddock could not. Another remedy for this position is to run the mower over any fields in which the whole or portion of the growth has run towards flower head development. This is a practice which is known as 'topping' the pastures. At times there is a tendency to delay the topping until it is far too late to obtain from it the full valuable effect it may have in prolonging the period of desirable, young, leafy fresh production. While the need for topping may occur on any fields which have not been sufficiently grazed, it is much more likely to occur on those which also have not been adequately harrowed. Indeed, on the latter, because of the development of rank, undesirable, unrelished growth round undisturbed animal droppings, topping may be advisable even when grazing of the greater portion of the field is reasonably close. Often when the topping is done at the right time, the amount of the mown material which results is so small as not to justify the gathering of the material for hay or ensilage. It will be found that the wilting which such material undergoes after mowing, results in the stock eating it much more readily than would be the case if it were not mown—such wilted material may be utilised by the stock so eating it, and this with special advantage if dry stock are available for the purpose.

Besides tending to retain leafiness in a pasture, topping prevents undue shading of desirable species. Weeds too are kept under control and prevented from seeding and spreading. As a rule topping should not be carried out just before a spell of dry weather is expected. If it is deemed advisable to do topping just before or soon after such a dry spell it certainly should not involve close mowing of the sward.

HARROWING OF PASTURES

The principal objects of the harrowing of pastures are:—

(a) The effective distribution of animal droppings which, if undisturbed for any considerable time, tend to make pastures uneven by the stimulation of patches of coarse, rank, unpalatable growth, whereas if the droppings are well distributed they exert a considerable and valuable fertilising effect.

(b) The cultivation of the pasture plants in such a way that more vigorous growth is stimulated, mainly because of improved aeration; such cultivation is likely to be of most value in the case of dense twitchy and sod-bound swards, of the type at times produced by paspalum and browntop, and on the other hand such cultivation may confer but little if any benefit on a vigorous sward not overcrowded with shoots.

For harrowing of pastures a grass harrow is as a rule most serviceable. It is more drastic than the chain harrow, which, however, can often be employed with advantage in conjunction with the grass harrow, as it assists in the distribution of droppings which the grass harrow dislodges.

As a rule harrowing of pastures should not be carried out during or just before a spell of dry weather. Apart from this, harrowing may advantageously be done at almost any season. Harrowing is likely to be specially needed in spring after the winter stocking, and again in autumn because of material accumulated from the summer dry spell.

Better distribution of droppings is effected for the same amount of work by harrowing up and down a paddock in one direction and then across the paddock at right angles to the direction of the first harrowing, instead of harrowing a paddock twice by going round and round in the one direction.

Drainage of Pastures

The general benefits of drainage have already been discussed. See Chapter 15.

Drainage has equally important effects on the health of live stock with which pasture farming is so intimately and directly concerned. The stock are the living agents which deal with the pasture produced.

Efficient utilisation is impossible without healthy, thriving stock. Poorly-drained farm conditions directly favour the ravages of disease. Among the disorders which are lessened by good drainage are such serious ones as troubles of the udder, foot rot, fluke, parasitic worms, tuberculosis, and calving troubles.

There are many thousands of acres of pasture land, mainly in the North Island, in which the limiting factor to increased production is presence of excess water in the soil.

Management when Good Drainage is not Practicable

At times, circumstances may make it impracticable to carry out drainage at a cost which will secure economical returns. When this is the case, it is not always necessary to leave the land in the occupation of the weeds and poor grasses which are encouraged by the water-logged condition of the soil. Experiments have shown that correct manuring may reduce the number of poor plants that become dominant due to wetness of grassland. This arises from the fact that a superior pasture species may be struggling for a foothold against adverse conditions, both of drainage and of fertility, and manuring, by increasing fertility, enables it to establish itself. This is often the case in regard to such valuable plants for wet conditions as meadow foxtail, *Poa trivialis*, timothy, *Lotus uliginosus*, alsike clover, and strawberry clover. At times there is a failure to obtain satisfactory results with these under moisture conditions which are suitable to them because the fertility is the limiting factor. Under such conditions, manuring is the proper course to adopt.

Where the soil is very wet, floating sweet grass and *Glyceria maxima* (formerly *Poa aquatica*) are suitable.

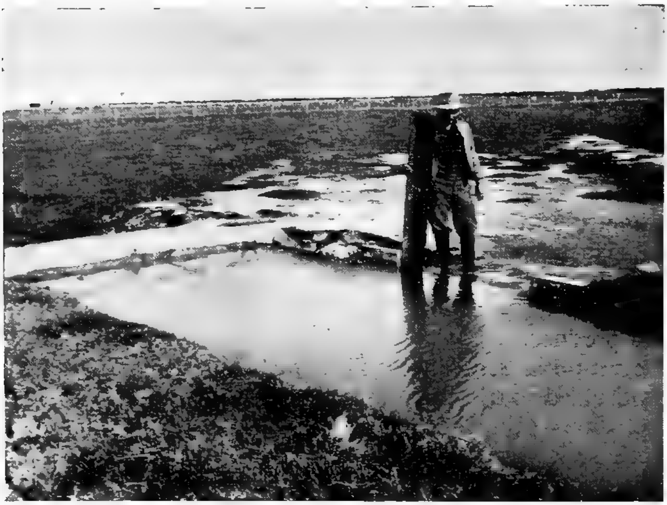


FIG. 89. Water flowing out of one of the headgates on to a border at the Winchmore Irrigation Station. Note the canvas dam

(*N.Z. Journal of Agriculture*)

IRRIGATING PASTURES

There are two main types of irrigation, surface irrigation by gravity from water races common in Canterbury and Otago, and sprinkler irrigation, from sources of water below ground level, carried out chiefly in the North Island.

Surface Irrigation.—Because the water with surface irrigation flows over the land by gravity it is the more economical method. The best means of control of this gravity flow on gently sloping land is by confining the water between low banks or dykes. This border-dyke system presupposes naturally gently sloping land little greater in fall than one foot per chain made even by grading before the pasture is established. The paddock is divided into long narrow strips with a gradual fall lengthwise but level crosswise. In the race bordering the paddock a canvas dam is opened and the water in sufficient quantity is allowed to flow over and across the strip in a sheet from dyke to dyke and then down to the lower end of the strip until it begins to overflow there. If the strips have been properly prepared according to the flow of water available, the type of soil and the slope of the ground, then the water will penetrate evenly to the required depth. (See Fig. 89.)

On steeper land or on uneven land other methods of control of the gravity flow are used such as ditches which are ploughed 50 ft. to 70 ft. apart at an angle across the slope. These ditches hold the water and let it overflow down the intervening slopes. On very steep land the ditches are built almost on the contours.

Sprinkler Irrigation.—There are large areas of land mainly in the North Island where surface irrigation is impracticable due to irregularities of surface and to lack of large supplies of water above the general ground level. In such areas sprinkler irrigation may be valuable. Water, usually lifted by a pump from river, creek, lake, or well, is forced by the pump through a sprinkler device to form a spray. This spray should be just fast enough to be absorbed by the soil and with drops of the best size, neither too small to cause undue losses by evaporation and wind drift nor too large to cause damage to soil structure.

Two systems of sprinkler irrigation are used. The high pressure system has large spray heads operating at pressures of 60 lb. to 120 lb. per sq. in., each head covering 1 to 3 acres. This system is useful where large areas have to be irrigated, where there is plenty of water available, and where the ground is very uneven. The more common system, however, is the movable pipe system working at pressures of 17 lb. to 30 lb. per sq. in. Some of its advantages over the high pressure system are:—(1) Being built of thinner materials it is easier to move about. (2) Working at lower pressure it uses less power. (3) With more spray heads to a given area it is less liable to produce uneven spreading in windy weather. As a check on the uniformity of distribution and the amount of water being applied several tin cans with vertical sides may be placed over the area to be irrigated. After an hour's irrigation the depth of water in each can is measured with a ruler.

It is only where soil moisture is frequently and regularly in short supply and where water can be made available abundantly and cheaply that irrigation of pastures is very likely to be economical. Where the summer is only occasionally very dry and where water has to be pumped from deep wells, then irrigation is unlikely to be economical and other methods of providing stock feed when pasture is scarce such as silage or a turnip crop have to be used.

If irrigation is warranted, then the most important questions to be asked are, how much water should be applied and how frequently? The quantity of water to apply will depend upon how much the soil will hold at field capacity and the depth to which the plant roots penetrate. The interval between irrigations depends to some extent on the texture of the soil but chiefly on the *evapotranspiration rate,* i.e. the rate at which water is lost from the surface of the soil plus the rate of loss by transpiration. (See pp. 72-76.) Effective irrigation must avoid the extremes. Too much water too frequently is wasteful in water and time, and may be harmful as, for example, by leaching, or by water-logging if the soil is not well drained. Too light and too infrequent applications will not attain the maximum yield. Probably the best way to avoid these extremes is to take soil samples with a soil auger before and after irrigating and to judge the moisture content by appearance and handling. Pasture appears to grow best when soil moisture is at or near field capacity. However, it is not possible to maintain this ideal soil condition at all times.

In addition to knowing how much water to put on his soil a farmer wants to know how long he can withhold irrigation before growth becomes adversely affected. Rukuhia Soil Research Station makes the following recommendations for sprinkler irrigation on North Island soils.

RECOMMENDED AMOUNTS OF WATER PER APPLICATION AT FIXED INTERVALS FOR VARIOUS MONTHS ON THREE TYPES OF SOIL

	*Amount of water per application				
	Nov. in.	Dec. in.	Jan. in.	Feb. in.	Mar. in.
Heavy soil:					
Irrigation at 10-day intervals	1¼	1½	1¾	1½	1¼
Medium loam:					
Irrigation at 7-day intervals	¾ to 1	1	1¼	1	¾ to 1
Light, sandy loam:					
Irrigation at 5-day intervals	⅔	¾	1	¾	⅔

* In particularly hot, dry periods apply 10 per cent more water.

If there is more than 0.2 in. daily fall of rain during the months of irrigation, then the intervals between irrigations may be extended by one day for every 0.2 in. of rain recorded. This means that every farmer practising irrigation must use his own rain gauge.

Because pasture production under irrigation is expensive, only the best pastures, those capable of responding well to added water, should be used for irrigation. The desirable species composition of such pasture is as follows:—perennial ryegrass, short rotation ryegrass, white clover and red clover, together with cocksfoot, or, in the warmer parts of the Auckland Province, together with paspalum.

Irrigation should be started during a dry period before growth has slowed up markedly. Otherwise the response to the irrigation will be slow. It is recommended that, after about a week of dry weather from October onwards and rain still not likely, irrigation should begin.

As with autumn-saved pasture, irrigated pasture should be grazed on the rationing principle, leniently and with adequate spelling. Soon after grazing the dung should be spread with harrows and irrigation repeated.

BENEFITS FROM IRRIGATING PASTURES

Pasture irrigation may be of direct benefit to a farm by increasing its carrying capacity and therefore raising farm production. It would seem correct to say that the costs of the irrigation spread over the life-period of the apparatus must be more than met by the increased production returns for that period. However, against the costs must also be placed other possible benefits of pasture irrigation. Some of these may be:—the prevention of the ingress of weeds into pasture which normally opens up during drought; improvement in the health of stock such as the avoidance of calving trouble; and reducing the necessity of supplementary summer feed such as silage and roots.

Exercise 4.—On a farm where irrigation is going on observe the checking of (a) the rate of delivery and uniformity of spread of the water, and (b) the sampling of the soil before and after irrigation.

Exercise 5.—On a school pasture plot in the summer try the effect on the pasture composition of applying water regularly with a watering can to one half of the plot leaving the other half unwatered.

SOD-SEEDING

In order to short circuit the conventional method of ploughing up, cultivating and resowing an inferior pasture, various methods have been used, chiefly by oversowing the existing sward with or without some kind of cultivation and by sod-seeding. On easy country where high soil fertility can be produced, sod-seeding appears to be the better of the two methods. Sod-seeding is a mechanical method of placing seed and fertiliser beneath a layer of cultivated soil. Parallel, plant-free tracks each 1½ in. to 2 in. wide and ½ in. to 1 in. deep are made across the pasture paddock with a suitable machine. Seed and fertiliser is sown at the same time in the middle of this track and is covered with a little soil. The phosphate in the fertiliser should be one other than superphosphate which may cause germination injury.

By this method both water and soil nutrients are close to the seed enabling germination and establishment to be rapid. Because of these good soil conditions and the fact that the seed is protected from birds, the rate of seeding can be low, 5 lb. to 10 lb. per acre. As a rule only quickly establishing species, perennial ryegrass, short rotation ryegrass and red clover are suitable for sod-seeding in high fertility pastures. Quick establishment is essential and lines of seed with high interim germination counts should be used. In order that the establishing seedlings may get sufficient light, the pasture must be grazed hard before sowing to remove as much growth as possible and to slow up its recovery. This should be continued after sowing and until the seedlings appear. Thereafter the grazing should be as for ordinary young pastures making sure that the new plants get sufficient light at all times. Where the initial fertility of the soil is not high, especially in respect to nitrogen, the fertility should be built up for some years beforehand by first sod-seeding with white clover and phosphate, together with perhaps medium fertility-demanding grasses like cocksfoot and dogstail. In certain situations, such as with sod-bound browntop and paspalum swards, where the competition from the existing sward is likely to be difficult or impossible to control, weedkilling chemicals are useful. These chemicals may be applied in a band just in front of each furrow opener of the sod-seeding machine.

SITUATIONS FOR SOD-SEEDING

(1) A clover dominant sward needs its grass content raised to a proportion of say two-thirds, in order that the store of available

soil nitrogen built up by the clovers may be used in grass production. Hence much higher production will result from such a sward after sod-seeding than before.

(2) Pastures dominated by poor grasses and weeds, such as browntop, Yorkshire fog and sweet vernal need the introduction of a perennial clover. (See the previous section.)

(3) Where, as commonly occurs on heavy, wet soils, autumn sown pasture growth could not be properly controlled in the winter and early spring resulting in poor clover establishment. After hard grazing in the spring, a fresh supply of clover may be sod-seeded along with phosphatic fertiliser.

(4) On crop stubble, provided there are no perennial weeds such as docks, twitches and Californian thistle present, sod-seeding may be practised with advantages not only of (i) economy in cultivation but also (ii) better consolidation of the seed-bed, (iii) quicker turning of the land back to pasture, (iv) gaining of additional grazing from the re-growth of the original crop, such as chou moellier and rape, or of seedlings of cereals, (v) less pugging of the soil during the first winter grazing.

Advantages of Sod-seeding over Normal Re-pasturing

(1) It is much cheaper because cultivating and sowing are combined in one operation.

(2) As the existing sward still has a useful amount of feed left on it, and as the ground is in production again much sooner, less stored food such as silage is required to maintain the farm livestock.

(3) There is less loss of soil through wind and water erosion.

UNPLOUGHABLE HILL COUNTRY PASTURES

About two-thirds of the farming land in New Zealand is hill country which is on the whole so steep that it cannot be cultivated by ploughs or discs. While many management methods used on ploughable country cannot be applied to hill country, there are some methods, notably the use of aeroplanes for topdressing, which enable striking improvements in the management of hill country pastures to be achieved. More clovers and more minerals are the main requirements of hill country. Given these, more stock can be carried on the hills giving more hoof-crushing power and more eating power to control secondary growth and to prevent the return of the vegetation cover to scrub and forest.

Topdressing then is the primary need of hill country pastures, but, being expensive, it must be very carefully considered. If the pasture has little or no clover in its composition, then it is a waste of time and money to topdress only with fertiliser. Clover must first be established because it is the supply of available nitrogen in the soil which is the limiting factor to pasture growth, and, until that supply is built up through good clover growth, no amount of phosphate will improve pasture production.

OVERSOWING

The introducing of clover seed of good strain into unploughable hill country swards is by oversowing. This means applying the clover seed by hand or by aeroplane to the existing sward which is usually uncultivated except by the hooves of livestock. On dry hills certified white clover seed, 2 lb. an acre, and certified subterranean clover seed, 3 lb. an acre, should be sown. On country with high rainfall and on all shady, damp slopes white clover, 2 lb. an acre, and lotus major, 1 lb. an acre, are required. March is the best month for oversowing except in high country where spring sowing is the rule.

Before oversowing, the pasture should be grazed closely to allow the seeds to reach the soil, but not so closely that the birds get too great a proportion of the seed and that the conditions for germination at soil level easily become unfavourable. It has been shown that if the pasture cover is removed by very close grazing the humidity at the soil surface falls so much and the temperature there rises so much that germination and growth are seriously affected. The seed is sown, together with phosphatic fertiliser, but not ordinary superphosphate, by hand or by aeroplane.

After oversowing the paddocks should be closed to stock for a period, usually of about three weeks, to allow establishment of the clover. Subsequent grazing until the next summer should be carefully controlled so that old plants are not allowed to shade out new plants but not so close as to cause the seedlings to be damaged by stock hooves. In the initial stages of clover establishment by oversowing even under good conditions, the clover plants are few and far between. Natural reseeding of these initial plants should be encouraged by spelling the pasture during the summer to allow the clover to flower and set seed. If the natural reseeding is likely to be insufficient, it is advisable to make another sowing in the following March. Not until a high proportion of vigorous clover is present will it pay to topdress again with fertiliser. Grasses can seldom be successfully established by ordinary oversowing.

WEEDKILLERS IN RELATION TO OVERSOWING

To avoid suppression of clover seedlings following oversowing, by competition and damage of the seedlings by early stocking, chemical weedkillers may be spread over the pasture before oversowing. By using this method grass seed as well as clover seed may be oversown to achieve the establishment of higher fertility demanding and higher producing species, and a rapid improvement of the pasture. It must be emphasised that the chemical method requires a sound knowledge of the effects of weedkillers before it can be used successfully on a particular farm. When applying the weedkiller the length of the pasture shoots should be 1 in. to 2 in. Dead cover of this height gives sufficient protection for the seedlings without undue shading. Spreading of the weedkiller may be made by aeroplane and should be carried out within two weeks of sowing. If the sowing is not done soon after the application of the weedkiller, weeds tend to become re-established from seed in the soil. The rate of seeding should be as for normal pasture establishment and fertilising also should follow the normal pattern. Grazing, however, must be specially carefully controlled as for all oversown pastures.

HILL COUNTRY TOPDRESSING

On steep hill country which is not topdressed the stock tend to move along a few tracks following the contours and to camp in a few specially attractive places like broad ridges and around lone trees. Therefore there tends to be on the hills two main kinds of pasture association. The one is of moderate to high fertility-demanding plants on the tracks and camp sites fertilised by the grazing animals, the other is of low fertility demanders on the steep slopes between the terraced tracks, that is on the 'riser' areas. A policy of oversowing and topdressing alters this. After establishment of clover by oversowing and topdressing with fertiliser, chiefly phosphate at the rate of about two cwt. per acre per annum, and perhaps also with molybdenum and lime, and with proper control of the grazing, more stock can be carried. The stocking rate may be raised from 1 sheep to the acre or less to 3 sheep to the acre or more, together with the necessary proportion of cattle required to keep the pastures under control.

This topdressing if adequate on the 'riser' areas will promote good clover growth and consequently grass growth and so will attract grazing. Thus, with a greater number of stock grazing more widely, stock tracks and stock camps become more numerous and animal fertilising more uniform. Moreover, if trees are space planted on the steep slopes, as discussed in Chapter 21, extension of stock camps will be still greater. Production of both pasture and livestock will be enhanced in terms of the fertility spiral already referred to.

Looking at hill country from another point of view, we see that, if the stock carrying capacity is one sheep per acre or less, there will usually be insufficient revenue per acre to allow regular topdressing. Hence the soil fertility must continually diminish and deterioration of the sward must follow. Soil erosion and flooding are common symptoms of this deterioration. Extra stock carried as a result of topdressing with clover and phosphate bring extra returns which allow regular topdressing. Extra stock void more dung and urine which help still further to build up soil fertility and to produce still more vigorous pasture. So the trend has now become reversed. Instead of pasture deterioration and soil erosion there is pasture development and soil conservation. (See Chapter 16.)

AIRBORNE FENCING

It is little use increasing pasture production on hill country if the extra pasture is not used efficiently by livestock. By efficient use is meant complete use of the extra feed by the maximum number of stock. There should be a minimum waste of pasture which has taken time, money and effort to produce. To achieve efficient use of the extra pasture growth closer subdivision is necessary. It has been estimated that for every 20 tons of phosphate applied to hill country one mile of new fencing is required. The difficulty of carrying heavy fencing material to rugged hill country has pressed the aeroplane into the service of hill country farmers for laying fencing as well as for topdressing. The weight and bulk of normal fencing materials has also promoted the use for hill country of the more portable galvanised steel fencing posts and battens. With many millions of acres of hill country responsive to oversowing and topdressing with phosphates and other fertilisers, the requirements for subdivisional fencing to convert the land from extensive grazing to intensive grazing are great indeed. The rate of this conversion depends upon the prices being obtained for farm produce and upon the will and skill of farmers and of those connected with farming.

Exercise 6.—On a hill country farm observe the composition of the pasture in the following kinds of places:—(a) Stock tracks; (b) Stock camps; (c) Sunny slopes; (d) Shady slopes; (e) Valley bottoms; (f) Area regularly topdressed and similar area not topdressed.

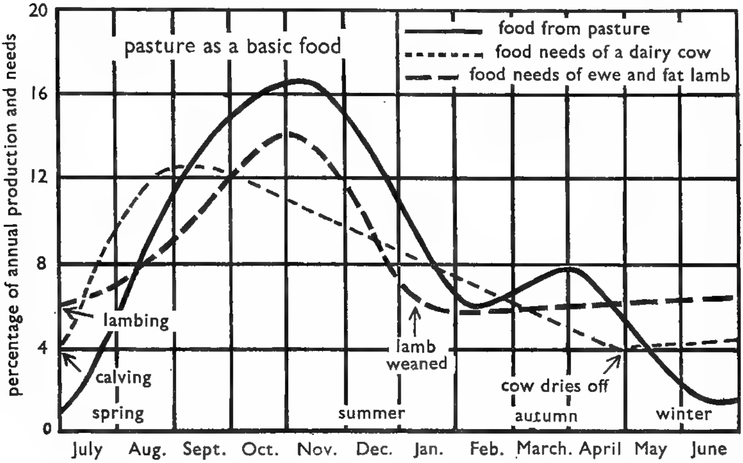


FIG. 90. Pasture production in relation to animal production and needs (*After McMeekan*)

MANAGEMENT OF PASTURE IN RELATION TO ANIMAL PRODUCTION AND ANIMAL HEALTH

Not only do grazing animals affect pasture but also pastures affect grazing animals. Let us consider some of the latter effects.

As seen in the diagram given above the feed supply from average pasture fluctuates considerably. Growth begins vigorously in September and reaches a peak in October-November. Falling away rapidly in the summer, the food supply from pasture then becomes insufficient for the needs of dairy cows. Rising again with the autumn rains the supply becomes sufficient for two or three months only to fall to the lowest level in the winter. Vagaries of climate from year to year, however, tend to make the fluctuations in available feed even greater than those represented in the diagram. This is especially so in the spring.

Efficient farmers make provision against such fluctuations either by saving adequate supplies of hay and silage and of autumn-saved, winter-stored pasture or by the use of special purpose pastures such as prairie grass or phalaris or of special crops such as turnips or by irrigating in the summer. By so doing farmers ensure that the health and productivity of their stock are maintained at high levels. Stock can be brought through the winter on a rising plane of nutrition and lush spring growth can be balanced with more mature grass and with hay and silage; thereby nutritional diseases such as milk fever, grass staggers and sleepy sickness can be avoided.

Facial eczema disease, largely associated with the vigorous autumn recovery of improved ryegrass strains, can be controlled by careful stock management. Due to a poison present in quickly growing grass, control of this disease rests entirely in preventing stock eating pasture at its poisonous stage which occurs almost immediately and for a few days after ½ in. or more of rain has fallen following a dry spell in the months of January, February and March. Mature pasture at this time is safe, but on high fertility soils lacking water such pasture is not easily available. Pasture composed almost wholly of clover is also safe. Good stocks of hay are essential for feeding sheep shut up at the rate of 200 an acre during periods of facial eczema danger.

Similarly bloat disease of cattle is associated with improved clover strains. Control of this trouble by pasture management is difficult. When herbage is lush and especially when clovers are abundant, there is danger of this and other digestive troubles. Rationed grazing of dangerous pasture helps. The use of special purpose pastures containing little or no clover is another means of control. Pastures consisting dominantly or exclusively of phalaris or of prairie grass have been shown to be valuable in this connexion.

Pastures containing too much clover also may cause undesirable feed flavours in milk and cream. The presence of some weeds in dairy pastures, notably land cress even in small amounts, causes heavy tainting of milk and cream. In the short run grazing management is the only means of preventing the tainting. A herd should be grazed on tainting pastures immediately after milking and not within four hours of milking. In the long run pastures should be so managed that clover is not unduly prominent, and that tainting weeds are eliminated by some means such as the application of selective weedkillers, sod-seeding or a programme of paddock-by-paddock ploughing up and resowing.

Heavy stocking of pastures calls for preventive measures against parasitic infection. With dairy calves, grazing of the calves on the pastures rotationally ahead of the milking cows usually keeps the calves free from internal parasites. With sheep, especially hoggets, rotational grazing similarly helps to keep down internal parasitic infection.

There is much to be discovered about the effects of pastures upon the animals grazing them and of the animals upon pastures, especially with intensive farming. The more a farmer knows about the principles of pasture ecology the more efficient he is likely to become in his pasture management.

READING

'Pasture Production in New Zealand', Saxby, S. H.
N.Z. Dept. Agriculture Bulletin, No. 250

Grasslands of New Zealand, Levy

Introduction to Plant Ecology, Tansley, Sir Arthur

New Biology, No. 6

Rural Education Bulletins, Feb. to May 1953, Nov. 1955

Cant. Chamber of Commerce Agriculture Bulletins, Jan. 1957, Mar. 1956, Jan. 1955, July 1954

N.Z. Journal of Agriculture, Mar. 1958, p. 227; Feb. 1958, p. 106; Jan. 1958, p. 17; Mar. 1952, p. 225; Jan. 1951, p. 49

Soil Conservation Bulletin, No. 12

19

Farm Crops

Of the improved farming land in New Zealand only about one million acres, or one twentieth, is used for annual crops, the rest being used mainly for the perennial crop, pasture. Annual crops, however, are of great importance not only in providing food directly for human consumption, such as wheat and potatoes, but also in providing human food, such as meat and cheese, indirectly by supporting perennial pasture for animal production. Pasture support by annual crops is brought about in two ways:—first by supplementing pasture during periods of poor pasture production, and second by being an intermediary in the process of improving pastures.

Few farms in New Zealand are devoted entirely to cropping. Where cropping is a prominent feature, that is generally in regions with annual rainfall of 25 inches to 40 inches and with hot, dry summers, there is usually *mixed farming* in which annual crops are grown not only for sale (*cash crops*) but also are grown to supplement the feed of livestock (*supplementary crops*).

Growing cash crops tends to reduce soil fertility. This is mainly because the necessary cultivation accelerates decomposition of soil organic matter so necessary for holding moisture and plant nutrients and for maintaining good soil granular structure. Available plant food is also removed in the crop sold. Forage crops eaten *in situ* and perennial pasture, combined with fertilising, restores this fertility. It is this need for maintaining a balance between exhaustive cropping and restorative cropping which makes mixed farming play so prominent a part in crop production in New Zealand.

With improved varieties of crops, with better machinery for cultivating and harvesting, and with better control of crop diseases and pests, annual crops could play an even more important part in New Zealand farming than they do at present, and thus achieve still higher per acre production of farm products. In many parts of the South Island annual crops are essential to farm prosperity.

ROTATION OF CROPS

Rotation of crops is the growing of a number of crops in regular order instead of the same crop on a particular area year after year. In general, as experience ripens and as agriculture becomes somewhat advanced and intensive, rotational systems are evolved in regions in which the growing of arable crops is important. The reasons for rotation of crops briefly are:—

1. Certain crops, e.g., barley and maize, are shallow-rooted; others again develop a deep root system, e.g., mangels, wheat, clover and lucerne. By periodically alternating deep and shallow-rooting crops, the soil as a whole is laid under contribution.

2. Though all crops require the same kind of food substance, yet their requirements in the matter of quantity vary considerably. Hence, to continue growing a single crop may seriously deplete the available supply of some particular ingredient.

3. Crop diseases and insect pests are checked by crop rotations. Fungi, especially, linger in the soil from one crop to the next crop of their particular host. Some can be starved and destroyed if the interval between any two crops affected is made sufficiently great.

4. Rotational farming provides for a full and economical use of all the farm labour throughout the year, and obviates either a rush of work or a slack period. This is because different crops are best sown, cultivated, and harvested at different times.

5. Certain crops leave the soil in an excellent condition, both mechanically and chemically, for the succeeding crop. Thus the necessary cultivation and manuring is reduced to a minimum.

6. Satisfactory rotations usually will include crops which are regularly cultivated between the rows during the growing period. Such 'cleaning' crops help considerably in keeping weeds in check, e.g., potatoes and mangels.

7. Rotational cropping results in a variety of produce which is available for stock at different seasons. This renders possible the economical and efficient feeding of live stock; and the system of farming which involves raising stock is the one which most tends to maintain the fertility of the soil.

8. The inclusion in the rotation of a leguminous crop, or of pasture containing clover, enables the soil to be periodically enriched with nitrogen.

TYPES OF ROTATIONS

Rotations are spoken of as 2, 3, 4, etc., 'course' according to the number of crops included. The four-course rotation which originated in Norfolk, and which, with modifications, has been adopted in many parts of the world, is worthy of study. It consists of:—

1. Root crops—turnips, and swedes partly consumed on the land and partly stored at the homestead. Often carrots, mangels, and potatoes may well be substituted partly, at least, for the turnip crop.
2. Barley or oats.
3. Red clover, usually with some Italian ryegrass.
4. Wheat.

The cropping would be as follows:—

YEAR	NUMBER OF FIELD			
	1	2	3	4
1st	Turnips, etc.	Barley or Oats	Clover and Ryegrass	Wheat
2nd	Barley or Oats	Clover and Ryegrass	Wheat	Turnips, etc.
3rd	Clover and Ryegrass	Wheat	Turnips, etc.	Barley or Oats
4th	Wheat	Turnips, etc.	Barley or Oats	Clover and Ryegrass
5th	Turnips, etc.	Barley or Oats	Clover and Ryegrass	Wheat

In New Zealand the Norfolk rotation is seldom, if ever, rigidly followed, for farmers find that its advantages are outweighed by various local conditions which are encountered. Often pasture is the main consideration.

In the cereal-growing belts of New Zealand the cropping system is often on the lines of the Norfolk rotation, with the important modification that the temporary pasture stands for from 3 to 8 years, by which time it has usually deteriorated so seriously as to necessitate ploughing up. For mixtures used see Chapter 17.

In framing a system of cropping or in determining whether rotations are even advisable, many factors must be considered. The rotation suited for a warm, moist climate would prove ruinous in a drier, cooler region.

Again, the character of the soil sometimes forbids cropping, and calls solely for the laying down of permanent pasture to the best advantage.

Further, the situation, in respect to the transport and marketing of produce, must be considered. In brief, rotations must be carefully adapted to local conditions, and on some types of soil are not advisable.

CEREALS

NATURAL ORDER: Gramineae

WHEAT (*Triticum sativum*)

With increasing population in New Zealand more and more wheat is required. Given good prices for wheat, the use of varieties suited to the district, and good farm management, New Zealand should be able to grow all its own wheat.

SOIL AND CLIMATE

For the production of wheat yielding flour of high baking quality the climate must be one of abundant sunshine, and the atmosphere must be comparatively dry. Moreover rust is a serious consideration in districts having a warm and moist climate. The flour from grains grown under somewhat moist, dull conditions yields a smaller, closer loaf than the flour from the smaller, harder grain grown in the drier, sunshiny situations, although varietal differences are perhaps even more important.

Provided the climatic conditions are suitable the heaviest crops are grown on the richest land. Much of the very best wheat land is now used for dairying and fat lamb raising, so that the bulk of the wheat is grown on medium to light land. Wheat in New Zealand has never been extended to the very light land. Canterbury affords ideal conditions for wheat growing, and we find this province producing over 67 per cent of our total production.

POSITION IN ROTATION

This varies with the district but usually depends upon the need for renewing pastures and the provision of supplementary feed for live stock. One of the best places is after peas, pasture, or red clover. These deep-rooting, vigorous legumes leave the land in a friable condition and also accumulate nitrogen so that a good crop is ensured with the minimum of cultivation and of manure. A favourable sequence is wheat after rape. Here again the land is easily worked, and is available at the right season, and the manure left by the stock may be expected to have a beneficial effect on the wheat. Spring sowing should be adopted only when circumstances necessitate it, for the autumn is the ideal season for sowing because seeds establish themselves while the soil is still warm, and then during the winter, though the plants seem to be at a standstill, they tiller and develop a considerable root system which facilitates vigorous growth in the spring.

Growing wheat after pasture is a frequent practice and gives good results, but only when a special procedure, described below, is adopted.

Wheat may also be very suitably sown after potatoes, which if dug as soon as they are ripe will leave the ground clear sufficiently early for the wheat, which can be sown with a minimum of cultivation and of manure, and yet with the assurance of an excellent crop.

CULTIVATION

Wheat, like most of the valuable members of the grass family, needs a fine but firm seed-bed. The necessity for firmness is established when we remember that a superior growth generally is to be found at the headland, where the soil has received additional firming by the turning of implements. The necessity for firmness often makes it possible to dispense with ploughing after peas or potatoes, the wheat being preceded merely by two or three discings. It is not desirable to work the surface soil too finely, for the fine particles have a tendency to cake. Small lumps are no disadvantage provided they are on the surface; they give the seedlings shelter during the winter and gradually break down into a fine, loose surface.

Ordinarily, the following cultivation may be practised:—After grass or clover, skim-plough in March or earlier and let the land lie for six or eight weeks; then disc to a fine tilth and plough to a depth of six inches. This puts the tilth to the bottom and the lumps to the top where they can be reached with harrows, which should be used till the soil is sufficiently fine; then the land should be rolled, cultivated, and finally the seed sown. When wheat is sown after rape, peas, or potatoes, the skim-ploughing and first discing may well be omitted. After oats or wheat it is not generally wise to sow wheat, but sometimes it may be advisable. The stubble should be first disced or grubbed to encourage the sprouting of weed seeds and to obtain a fine tilth which should later be ploughed down to a depth of five or six inches. After drilling, it is well to harrow so as to bury all the seeds to the same depth. In spring when the wheat is three or four inches high it is well to harrow again. This may seem drastic treatment, but in reality it kills few or no plants for they have already developed a strong root system. On the other hand, it breaks the crust on the soil and so conserves moisture, and it probably also stimulates the desirable tillering habit. Sometimes the wheat is fed off by stock before harrowing. Trials in New Zealand indicate that feeding-off should be practised only if the crop is rank and tends to 'go down' or if sheep feed is acutely needed.

FERTILISING

The fertilising ingredients most required by wheat are phosphorus and nitrogen. Our soils, as a rule, contain sufficient nitrogen, especially if a legume such as peas or clover has preceded or if lea has been turned down. Sometimes, however, it is advisable to supply nitrogen, especially if the crop is inclined to be light in colour, during August or September. This is best done by topdressing about 1 cwt. per acre of some soluble nitrogenous fertiliser, such as sulphate of ammonia or nitrate of soda, during the month of September.

Generally 1 cwt. of superphosphate may be used with profit, since this would be repaid by an increase of 1 to 1½ bushels per acre. Where formerly the increase would have been around 4 to 6 bushels this has steadily decreased due no doubt to the concentration of phosphorus in the soil from previous applications of phosphatic fertilisers and the steady improvement in fertility from better pastures and topdressing.

THE SEED

The seed should be machine dressed to remove small, shrivelled, broken grain and odd straws. The quantity of seed to use varies with the district, time of sowing and variety. In Canterbury and Marlborough it is usual to sow from 1½ to 1¾ bushels per acre. In Southland 2 to 2½ bushels is not considered excessive on rich land or when sowing in the spring or with varieties like Cross 7 which do not tiller much.

Varieties:—The following wheat varieties are recommended by the Department of Agriculture:—

South Island

Autumn sowing:	
Marlborough	Hilgendorf, Cross 7.
Canterbury	Aotea, Arawa (heavy land), Hilgendorf, Cross 7.
North Otago	Aotea, Arawa (heavy land), Cross 7.
Spring sowing: South Otago, Southland	Cross 7.

North Island

Spring sowing: Rangitikei, Manawatu, Hawkes Bay, Wairarapa.	Gabo, Tainui.
Spring sowing: Wairarapa	Cross 7.

Certification of wheat for seed ensures varietal purity and freedom from seed-borne diseases such as loose smut and stinking smut.

Weed Control

Using a suitable hormone preparation at the correct stage of growth of the wheat, most weeds are checked or killed without crop damage. When tillering of the wheat has occurred, the hormone spray should be applied as soon as possible to destroy the seedling weeds while they are seedlings and therefore most vulnerable. A later spraying may be required for weeds, such as Californian thistle and dock, which have developed from stems and roots in the soil and which are most vulnerable near flower-head formation. This second spraying should therefore be made as late as possible between the jointing stage and the stage called the boot stage when the head is just about to shoot.

Harvesting

The ripening changes go on continually from the root upwards, and in respect to the grain three stages may be easily distinguished.

(a) Milk ripe—the grain contains much water, and when squeezed a milky white juice oozes out. Although some of the leaves are dead, the whole crop presents an unripe appearance.

(b) Yellow ripe—the grain on being crushed appears doughy, and the straw has assumed a yellow tint, with the exception of about 3 inches below the ear. The crop is then probably at its best for harvesting.

(c) Dead ripe—the whole straw and head is dry, shrunken, and brown; the grain is firmer and brittle. The straw is also often brittle. To leave the wheat to this stage will not increase the yield, and there is great danger of loss through wind or other unfavourable weather.

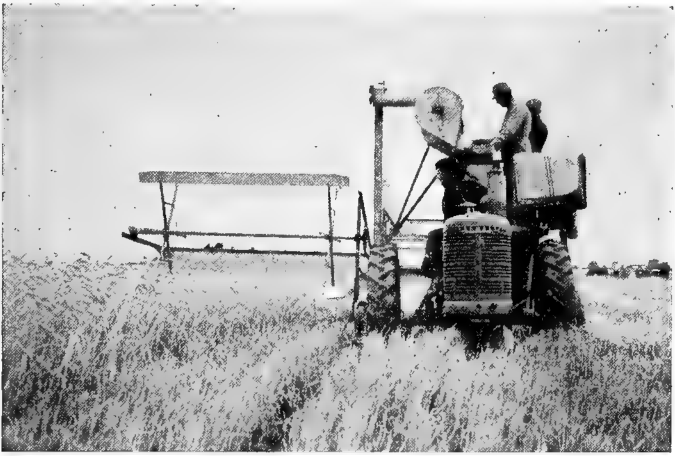


FIG. 91. Harvesting wheat, Canterbury
(*N.Z. Journal of Agriculture*)

Crops cut with the reaper and binder in the yellow-ripe stage, if properly cared for, ripen completely without loss of quality and without shedding of grain by wind. The sheaves should be left in stook for 14 to 21 days, according to the dryness of the weather. Most crops are threshed direct from the stooks, but stacking the sheaves for three weeks or more before threshing results in a better-quality sample.

Today 90 per cent of the wheat crop is harvested in header-harvesters, machines which reap and thresh the grain in one operation. The crop has to be dead ripe and the grain dry (below 17 per cent moisture) so that it will not 'sweat' in the sacks. Leaving the crop to this stage entails a certain amount of risk of damage by wind and moisture, but with modern varieties this risk is not great, and the cost of harvesting is considerably reduced.

OATS (*Avena sativa*)

SOIL AND CLIMATE

Milling oats are best grown in a cool, moist climate. In a dry climate, except on soils which hold water, a long, thin grain with a thick husk is developed, and this type of grain is unsuitable for milling. Oats prefer a well-drained clay or clay loam. The crop is, however, one that may be grown satisfactorily under many conditions of soil and climate provided the right variety is selected and, in Canterbury, is extended on to land too poor for profitable wheat growing.

VALUE AND USE OF OATS

The oat grain has about the same general composition as wheat, but there is a tendency towards a higher percentage of the valuable nitrogenous compounds and the grain is also characterised by a higher proportion of fat.

Oats may be grown:—(1) To provide grain for milling, Garton's Abundance, Onward and Milford being the chief varieties used. (2) To provide grain for feeding stock using the varieties Garton's, Algerian and Duns. (3) To provide chaff, nearly all varieties being used, but Algerian and Duns usually producing the best. (4) To provide green feed to be eaten off by stock or cut and fed out to them, Algerian, Duns and Winter Grey being favoured varieties.

In warm, moist situations, as in the North Island, the Algerian oat is preferable because of its resistance to leaf rust. It is best sown in the autumn, and may be fed off in the spring and then left for seed or for chaff.

It is well known that oats are specially well adapted for the feeding of horses; this is because of their mechanical condition and the character of the available nutrient substances.

Crops to be used for chaff should be cut when the grain is still in the dough state. This secures a more appetising feed with the nutrient substances evenly distributed. Thorough ripening involves accumulation of the nutrients in the grain, and the straw becomes brittle and unattractive to stock.

BARLEY (*Hordeum sativum*)

Barley is a surface-rooting crop and therefore does not resist drought well. It is grown for malting or for stock feeding. The best quality malting barley is grown on rather light, well-drained soil—sandy and calcareous loams not markedly rich in nitrogen.

These produce medium yields of bright grain. Good malting barley contains much starch and as little protein as possible. The two-rowed varieties Research, Kenia and Carlsburg are the best malting varieties. They are sown at 1½ to 2½ bushel per acre, with 1 cwt. of superphosphate.

For stock-feeding purposes the type of soil is not of importance. Heavy yields of grain and straw are secured on fertile soil, from the six-rowed variety Cape, and while the grain is unsuitable for malting it is of higher feeding value for stock. Wong, Cape and Black Skinless are varieties for the production of green feed for stock.

The sowing of red clover and pasture seeds in the spring on a barley crop that has already been sown is a common and economical practice. After the cereal crop has been harvested the clover or pasture becomes established, and for this purpose barley is undoubtedly the most useful cereal.

RYE (*Secale cereale*)

Rye, or ryecorn, being very hardy, may be grown on poor, sandy soil on which other cereals will not succeed. It is suited for autumn sowing to provide green feed in winter and early spring. About 1½ to 2 bushels of seed per acre is sown. An improved variety C.R.D. is frost-resistant, tillers well, and recovers well after grazing.

MAIZE (*Zea mays*)

Of all the cereals in the world, maize is produced in greatest amount. This may be surprising considering that rice is the staple diet of half the human race, but most of the maize grown is used for feeding livestock, notably pigs. The great home of maize is the corn belt of the United States of America.

SOIL AND CLIMATE

This crop thrives best when favoured with a long, humid summer; hot days, warm nights, and intermittent rains with abundance of clear, sunshiny weather between. In the best maize-growing countries the mean mid-summer temperature is from 75° to 80° Fahr. To grow successfully the high-yielding varieties a long growing season is necessary. Where the growing season is short, quick-maturing varieties are grown, and these are generally poorer grain producers.

The soil best suited for maize growing is a deep, rich, friable loam, well supplied with organic matter. These conditions are found on many river flats, and provided the climate is suitable, they give heavy yields of both grain and fodder with very little artificial manure.

Soil and climatic conditions suitable for maize growing are to be found in several parts of the North Island, notably the Bay of Plenty and Poverty Bay.

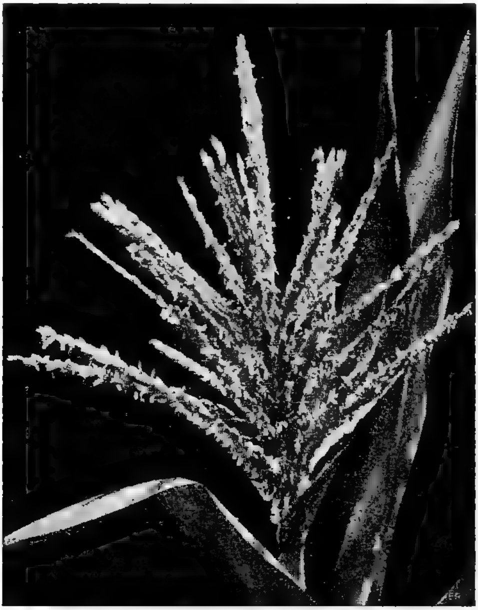


FIG. 92. Tassel of a maize plant
(*N.S.W. Dept. of Agriculture*)

PLACE IN ROTATION

Maize can follow pasture, peas, pumpkins or chou moellier. With fertile soil it may be grown on the same ground for several years in succession, provided that the crops are kept free of disease, the soil structure is not impaired and weeds do not develop excessively.

SOWING

This should not take place till all danger of frost is over. A special seed drill known as a 'corn dropper' or maize planter of 2-row or 4-row type is generally used.

For grain crops the drills should be about 30 inches to 36 inches apart, and the seed dropped at intervals of 9 inches to 10 inches in the drill and 4 inches deep. This will require from 12 lb. to 18 lb. of seed per acre. For green feed and silage drills should be about 3 ft. apart, and from 15 to 25 lb. of seed per acre should be sown. Lighter sowings result in coarse, hard stems, which are not relished by stock as green feed.

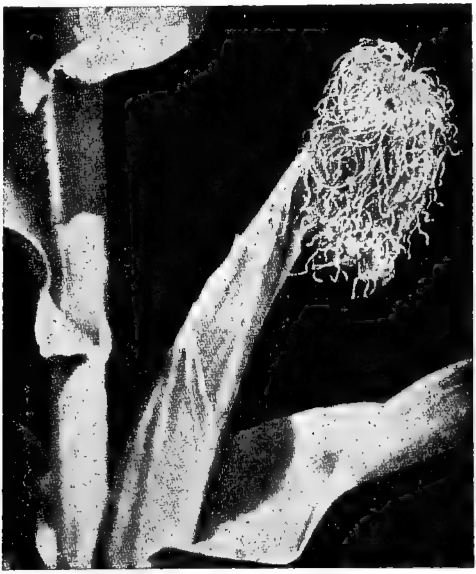


FIG. 93. Silk of a maize plant
(*N.S.W. Dept. of Agriculture*)

VARIETIES

Double hybrids such as Pfister 360 and Wisconsin 643 give the best yields of grain. (See Chapter 7.) For green feed Marigold, Hickory King and Early Butler are suitable.

WEED CONTROL

Pre-emergence and post-emergence harrowing will deal with the seedling weeds in the early stages. As soon as weeds appear after the last harrowing, spraying with 2, 4-D hormone should be carried out in still weather with low pressure spray so that spray drift is obviated. Just before the plants become too tall and thick for implements, they should be given a shallow moulding by forcing soil against the bases of the plants to a depth of about 6 inches. This helps to anchor the plants against wind.

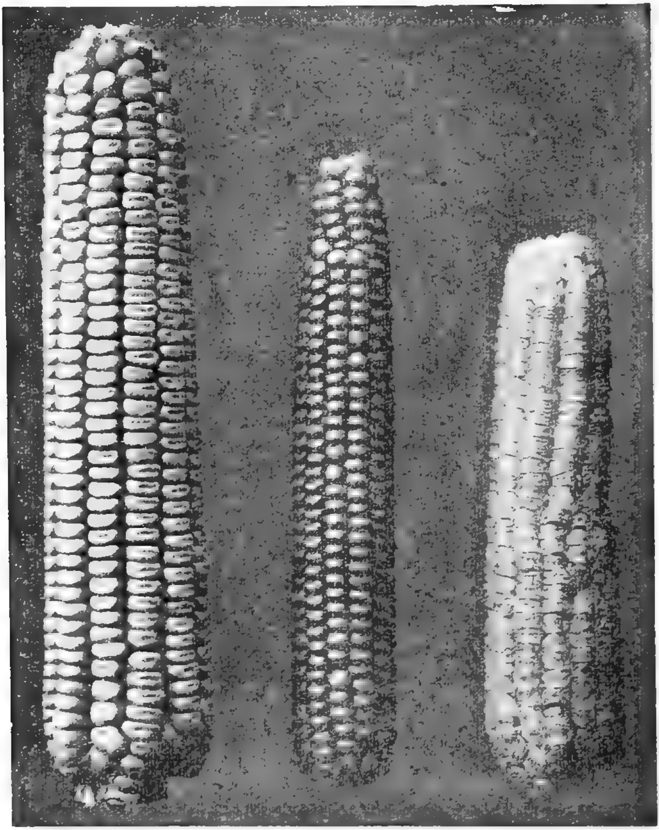


FIG. 94. Types of maize. *Left*: Dent maize; *Middle*: Flint maize; *Right*: Sweet corn

POLLINATION

Cross-pollination takes place by the aid of wind, pollen grains being transferred from the tassels of one plant to the silks of the cob on another plant. (Figs 92 and 93.) Unfavourable conditions for the transference of pollen, such as continuous rain during the flowering period, results in barren cobs.

HARVESTING

As green feed, maize can be cut and fed at any stage of growth. The most profitable time to harvest for silage is when the grain commences to glaze and the indentations are well marked. The crop is allowed to become dead ripe if intended for grain, and picked during the months April to June, but harvesting should be completed before any severe frosts occur. One method is to pull the cobs by hand, and cart them away to a shed to be husked as opportunity offers, or to husk while harvesting. Machine pickers, single-row type or two-row type, are also used to take the cobs from the plants, strip off the husks and deliver the cobs to a vehicle alongside. In all cases the cobs are allowed to become thoroughly dry, and are then shelled by means of a corn sheller. When a large quantity of maize is to be handled, special cribs are generally made of lattice work which allows of thorough drying and ventilation during storage.

USES

As green fodder, maize is useful on dairy farms in the North Island for summer feeding. The grain is used mainly for feeding poultry. With modern mechanisation of planting, cultivating and harvesting, weed control by chemicals, the sowing of double hybrid seed, and good prices, the very great demand for maize grain in New Zealand could be satisfied economically by New Zealand farmers.

A variety of maize called SWEET CORN (*Zea mays saccharata*) is grown by home gardeners and also for canning. Another variety, POP CORN (*Zea mays everta*) is also grown to a small extent. The latter variety has a very hard outer endosperm and a soft, starchy inner endosperm. When the grain is heated, the water inside develops pressure which suddenly overcomes the resistant coat bursting the grain open and turning it inside out.

MILLETS (*Panicum* sp.)

Millets are grown extensively in some countries for the production of grain, but in this country their cultivation is limited to fodder purposes.

The economic value of millets in this country lies in the fact that under favourable conditions, they will mature in 2½ to 3 months, and thus constitute a valuable catch crop. The green fodder is especially valuable for dairy cattle, and is very well relished. As a general rule millet is broadcasted at the rate of 10 to 15 lb. of seed per acre. In drills considerably less seed is required, but with thin sowing the plants are inclined to grow coarse and unpalatable, especially if the crop is to be cured as hay. Japanese millet is the usual variety sown. Broom corn millet must not be used for green feed, for, though its grain is used for feeding small birds, its leaves are poisonous.

BRASSICAS

NATURAL ORDER: *Cruciferae*

Most plants of agricultural importance in this order belong to the Genus *Brassica,* which includes swedes, turnips, rape, kale, chou moellier, kohl-rabi, mustard, cabbage, cauliflower, radish, and Brussels sprouts.

The flower has four petals which often resemble a cross. There are six stamens, four with long filaments, and two with short filaments. Cross-pollination is effected by insects, but self-pollination does take place, and good seed is produced in each case. A considerable quantity of oil is stored away by these plants as reserve food material, and seeds of several species belonging to the genus *Brassica* furnish oil which is sold under the name of colza or rape oil.

Most cruciferous crops are subject to insect damage which may be serious. Aphids, white butterfly, diamond-back moth and springtails all attack these crops, especially turnips and rape. Spraying with lindane at ½ lb. to 1 lb. per acre according to the degree of infestation will control these pests.

TURNIPS (*Brassica rapa*), SWEDES (*B. napobrassica*)

Of all the annual fodder crops grown in New Zealand, turnips and swedes together make up a far greater area than any other. They grow well under a wide range of soil and climatic conditions.

CLIMATE AND SOIL

Both soft turnips and swede turnips do best in a somewhat damp, dull, cool climate—the coolness being desirable chiefly because it does not favour various insect pests.

The best soils for their growth are open loams with a free subsoil. Soft turnips can be successfully grown on comparatively poor soil, but swedes require a moderately good loam and a cooler climate.

Cultivation

A fine, firm seed-bed is needed. The turnip crop, however, often follows a cereal crop to clean the soil of weeds which the cereals allow to become established. When this is the succession, it is wise to use the cultivator instead of discs, particularly if twitchy weeds are present, for the cultivator will bring the weeds to the surface, whereas the discs merely cut them in pieces and thereby multiply the twitch plant.

Sowing

In the south sowing of swedes commences about October to November, and in the North Island as late as January. Soft turnips are usually sown later than swedes. Early sowing will give heavy crops, but the early crop is much more susceptible to dry rot, and for this reason late sowing is often practised. Soft turnips are usually sown in rows 7 to 14 inches apart, 8 to 10 oz. of seed per acre, and sometimes more, being sown. Swedes are also sown in this way if the areas are large, but for small areas 1 to 1½ lb. of seed per acre is sown in rows or ridges 28 inches apart, and the plants hand-thinned to from 9 to 12 inches apart in the rows. Ridging is especially advisable for the swede crop if the field is somewhat wet, and is inadvisable if it is open and liable to experience drought conditions in the autumn.

Regular intertillage is advisable for turnips when the distance between the rows makes this possible.

Fertilising

Superphosphate is undoubtedly the most effective fertiliser to use. To avoid germination injury a reverted type of superphosphate is advocated. (See Chapter 13.)

Varieties

(A) Soft turnips may be placed in groups according to the colour of the flesh and of the upper part of the 'root' above the ground.

(1) White-fleshed varieties though of low feeding value are rapid in growth, yielding a considerable amount of produce quickly, and grow successfully over a wide range of soil and climatic conditions. As they often deteriorate rapidly after maturity, they should be sown at a time in accord with the time when they are expected to be used.

Being one of the best crops for keeping up the milk supply of a dairy herd in hot, dry weather when pasture production is low, a soft turnip crop fits very well into a programme of pasture renewal. It is usually safe and easy to grow, and after break-feeding, the soil is left in good condition in preparation for pasture. During the autumn too, when there is danger of facial eczema from grazing pasture, a soft turnip crop may be used to supply the necessary stock food.

Suitable varieties in order of maturing rate, quick to slow, are:—N.Z. York Globe, N. Z. Red Globe and N. Z. Green Globe.

(2) Yellow-fleshed varieties.—In comparison with white-fleshed, these are more robust, slower in growth and less injured by frost, and hence suitable for feeding in winter. Though superior in feeding value to white-fleshed turnips, yellow-fleshed turnips grow well only in a cool climate, fairly fertile soil and with the plants well spaced. Good varieties are N.Z. Purple and Green Top Yellow, and, where clubroot disease is suspected, N.Z. Purple and Green Top Resistant.

(B) Swede turnips are the slowest in growth, the hardiest and the richest in nutrient material. They differ from soft turnips in the following ways:—

(1) The swede has a 'neck' or short stem marked with distinct leaf scars—this is absent on the soft turnips.

(2) The first foliage leaves of the swede are rough like those of the soft turnip, but of a pale sea-green colour, probably due to a waxy bloom; they are never grass-green. The later leaves keep the same colour, but are smooth.

Common varieties are:—Superlative, Grandmaster and Crimson King. Wilhelmsburger and Calder are less susceptible to clubroot.

RAPE (*Brassica napus*)

Because rape is so useful mainly for lamb fattening, it takes second place in a list of the areas devoted to the principal fodder crops grown in New Zealand.

SOIL

Rape will grow well on a variety of soils, but the ideal condition is a rich, friable, well-drained soil, well supplied with organic matter. It must be provided with a fine, firm seed-bed. It may come at almost any place in the rotation. Rape should not follow turnips, marrow-stem kale, or kale, for they belong to the same plant family, and are attacked by the same insects and fungi; but as it is a cleaning crop, it is often sown when a field has become weedy. As it is fed off, the soil is improved by the droppings of the stock, and consequently it may be followed by a cereal crop.

When sowing rape, mustard seed is sometimes added, as the mustard tends to minimize the heating tendency of the rape. Quite frequently grass seed is sown with rape.

Use

Under favourable conditions rape will be advanced sufficiently in its growth to turn stock on it in 7 to 10 weeks from the date of sowing. It is almost certainly our best lamb and sheep fattener, particularly when we remember the low cost of the crop and its ameliorating effect on the soil. In the warmer northern districts improved pastures have to a large extent replaced rape as a feed for lambs prior to Christmas. In the South Island lambing is much later, and the rape is required about January to February. It is a good forage crop for pigs and for cattle, but with milking-cows it is apt to taint the milk. When fed continuously it has a heating effect on stock, particularly on lambs, whose sufferings are indicated in severe cases by the ears swelling and drooping, and by the wool coming off in patches. Providing hay (lucerne) or chaff, changing to pasture at frequent small intervals, and allowing access to water and salt, are all precautions which will minimize the trouble.

The varieties in common use to-day are:—Broad Leaf Essex, Giant and N.Z. Club-root resistant, the last being recommended wherever this disease is prevalent.

Chou Moellier or Marrow-stem Kale

Due largely to its freedom from diseases and pests, chou moellier, including kale, takes third place among New Zealand's annual fodder crops. This crop, which is also known as marrow-stem kale, belongs to the cabbage family, being grown mainly for its foliage of which it produces a great bulk. The stems which are from 3 ft. to 7 ft. high are also edible if not allowed to get too woody. It is a valuable fodder, characterised by rapid and vigorous growth, and it is highly nutritious.

SOIL—

A good soil such as would suit cabbages, is demanded. Farmyard manure is a fine dressing for this crop. Phosphates should be supplied in quickly acting forms (superphosphate and basic superphosphate).

SOWING—

About 2 lb. of seed per acre is required to be sown in rows 2½ ft. to 3 ft. apart, and the seedlings thinned out to 2 ft. apart in the rows. Quite frequently this quantity of seed is sown through the ordinary drill in 7 to 14-inch rows and not thinned. The crop is often grown in combination with swedes.

USE—

If used with care it will not taint milk provided it is fed to cows just after milking. Its succulency and nutrients make it suitable for cows in milk, and it is also fed to horses, pigs, and poultry. It is also grown extensively for sheep, replacing swedes in districts where the latter crop does not thrive, largely owing to the soil being infected with club-root fungi.

KALE

Another member of the cabbage tribe, kale, also called 'thousand-headed kale', is grown for its leaf. It requires similar soil and fertilisers to chou moellier.

'Thousand-headed kale' is a useful crop, particularly for early spring feed—this, because of its hardiness. Kale is a better drought resister than rape, it does not suffer so much from pests and disease, and it is not so liable to taint milk. It is, however, not so palatable as rape, it does not provide feed so quickly from seeding, and it will not fatten stock so quickly.

Because of its hardiness, kale is a useful crop if sown in October, for feeding in the following spring. It is especially useful for ewes at lambing time.

THE POTATO FAMILY

NATURAL ORDER: *Solanaceae*

Agricultural plants of importance in this order are potatoes, tomatoes, tobacco, and egg plant.

THE POTATO (*Solanum tuberosum*)

The potato is a perennial which dies to the ground each season and grows again from the tubers or underground stems. Many of the varieties do not flower freely, and of those which do flower, a great number never bear fruit. This dearth of fruit is often due to lack of pollen, the stamens or male organs having degenerated. The fruit or 'potato apple' is usually a greenish globular berry containing small, white, kidney-shaped seeds embedded in the green pulp.

The tuber, popularly called a 'seed', is an underground stem, and the 'eyes' on it are equivalent to the leaf buds on the stem of a young fruit tree. From the eye a number of buds may grow.

SOILS FOR POTATOES

Soils for the potato crop should be mellow and friable such as a good sandy loam, or a good silt or clay loam, rich in organic matter.

Potatoes do best after grass, the land being prepared by autumn skim ploughing, followed by a deep ploughing in the spring, and subsequent working down with disc harrows and cultivator till a mellow, clean soil and fairly fine tilth is obtained.

FERTILISERS

The soil must be either naturally rich or adequately supplied with fertilisers. These should be distributed in close proximity to the tubers. Trenches are opened up and the fertiliser is distributed in a strip 4 in. to 5 in. wide down the drills before planting, or distributed as a ring round each set. The most profitable fertiliser would appear to be a mixture of approximately three parts of superphosphate to one part of sulphate of ammonia. For main crops on light land use 4 cwt. to 5 cwt. of this mixture per acre; on heavy rich land 6 cwt. to 7 cwt. For early crops the quantity may be greatly increased with profit, and the recommendation to the early-potato growers at Pukekohe is to use from 12 cwt. to 15 cwt. of superphosphate and 4 to 6 cwt. of sulphate of ammonia per acre—that is, from 16 cwt. to 21 cwt. of the three-to-one mixture. This probably represents the limit to the profitable use of fertilisers, and the average grower will use from 4 cwt. to 10 cwt., according to soil and the type of crop being grown.

Sulphate of potash at the rate of 1 cwt. per acre, mixed with the superphosphate and sulphate of ammonia, may be tried, but only on certain soils in New Zealand will the potato respond to this fertiliser. Lime and wood-ashes should not be used.

From 20 cwt. to 25 cwt. of 'seed' will be required to plant 1 acre. Uncut, medium-sized, well-shaped tubers, averaging about 2 to

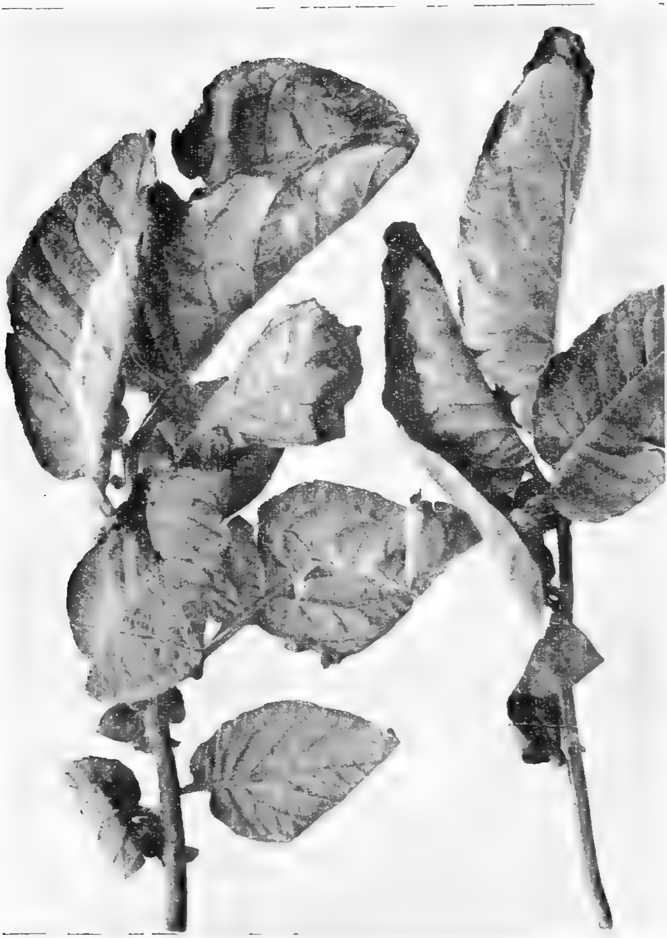


Fig. 95. Leaf-roll is a most serious virus disease in New Zealand. The infected plants may usually be identified by their smaller size, slightly paler foliage and upright habit of growth. On closer inspection the lower leaves are seen to be rolled upwards and become funnel-shaped as illustrated. These leaves are harsh and brittle to the touch and when shaken give a rattling sound (*N.Z. Dept. of Agriculture*)

3 oz. each are most economical. Many of the potatoes of this size come from the poor stalks in a crop. Using these smallish tubers without discrimination may easily accentuate the tendency towards deterioration by propagating mostly or wholly from the poor stalks of the previous season. To avoid such a result, table-size tubers may be cut and planted, or it may be necessary to select specially the seed for the following season from healthy prolific stalks.

SELECTING SEED

Healthy seed is a matter of paramount importance. There are perhaps more disappointments through the use of unproductive seed than through the combined effect of all other factors.

Potatoes are subject to *virus diseases* which bring about rapid degeneration. The symptoms can be seen in the foliage, but not in the tuber, hence the grower cannot know whether the seed he is buying is healthy or diseased. He may buy Aucklander Short-top seed and dig a 15-ton crop; another line of seed of the same variety, identical in appearance, may be capable of returning a fifth of that yield. So important is this one factor to potato-growers that the Department of Agriculture has a system of seed certification, and the produce of only those crops of approved cropping-power is passed as 'certified seed'. Any grower who does not insist on certified seed when purchasing his requirements is taking a serious risk of disappointment and failure.

Leaf-roll is a most serious virus disease of the potato. Severely infected plants may be identified by their smaller size and upright habit of growth. In all cases, even with slight infection, the lower leaves are rolled upwards and become funnel-shaped. These leaves are harsh and brittle. *Mosaic,* another serious virus disease, may be distinguished by a mottling and crinkling of the leaves. If the leaves are shaded from the sun the pale green mottling becomes more evident. In severe cases the plant is stunted and the leaves very crinkled. There are numerous other virus diseases, exhibiting specific symptoms. The diseases may appear singly or in combination, and the grower is well advised to suspect virus disease in all cases where the plants show abnormal or stunted growth. Virus spreads very rapidly in the growing crop, and infected plants should be removed as early as possible if it is intended to reserve seed from the crop.

Growers who retain their own seed should discard for seed purposes tubers from plants showing weak growth, mottled foliage, crinkled leaves, rolled leaves, harsh or brittle lower leaves, and

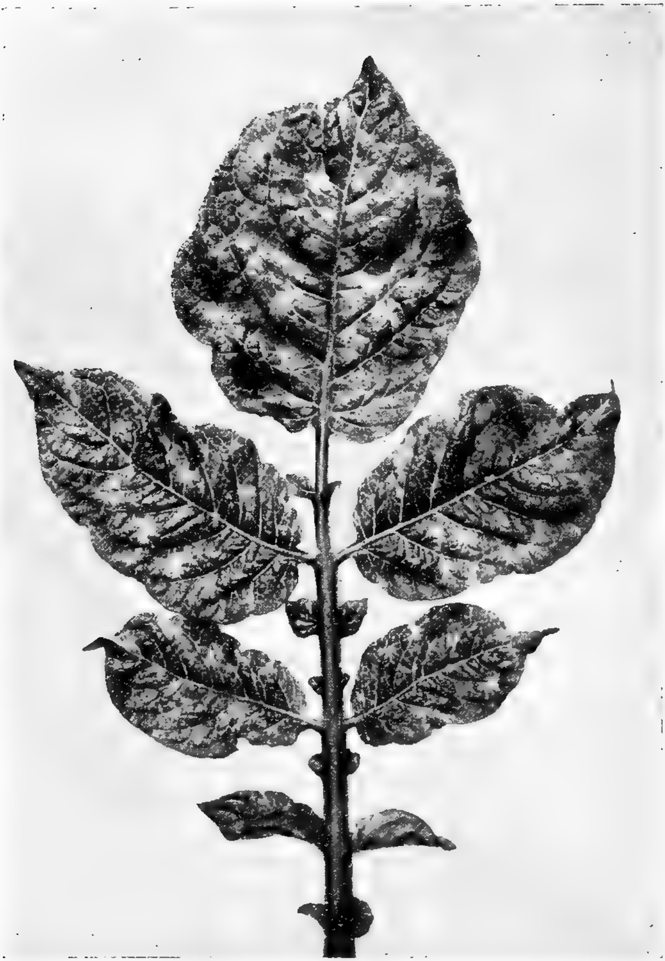


FIG. 96. Mosaic is a virus disease which may be distinguished by a mottling and crinkling of the leaves which are smaller than those in healthy plants. If an affected plant is shaded from the sun the pale green mottling becomes more evident. In severe attacks the plants may be much reduced in size, the leaves very crinkled and the mottling so pronounced as to make the whole plant appear pale in colour

(*N.Z. Dept. of Agriculture*)

those in which the parent tuber has not rotted at the time of digging. These are all symptoms of degeneration induced by virus disease.

Virus diseases are spread in the field by sucking insects such as aphids, and, since it is practically certain that there will be both virus disease and aphids in every crop, deterioration may increase rapidly, necessitating the purchase of fresh seed every few years. The presence of disease is the only reason why a change of seed is necessary, and therefore when making the change every precaution should be taken to introduce something better than that discarded. For this reason *certified seed* should be purchased.

PREPARING THE SEED

Seed may be stored on trays or in shallow boxes and given plenty of light. They will then green and produce short strong sprouts. Any tuber producing thin spindly sprouts should be discarded.

Whole seed is safest to plant, but large tubers may be cut, provided each piece has one or more strong eyes. An 8 oz. potato will make three to four sets. Some varieties, such as, for example, Majestic and Aucklander Short-top, will not stand cutting, but the danger of loss is lessened if the precaution is taken not to let the cut surface dry. It is, in fact, wise with any variety to plant and cover as soon as possible after cutting. To allow the cut surface to dry in the sun is to invite trouble. If cut tubers cannot be planted at once they should be spread on the floor and covered with wet sacks.

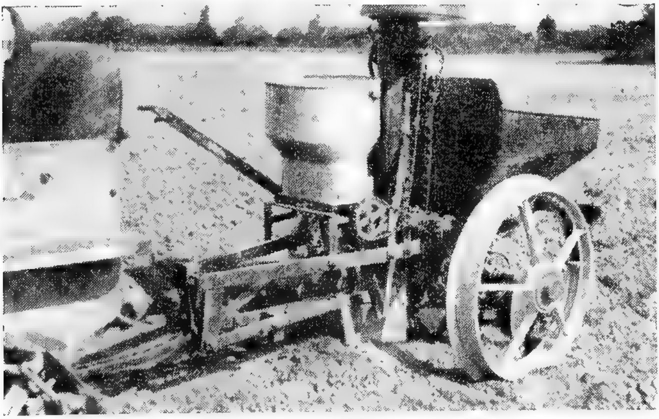


FIG. 97. A potato planter at work

PLANTING

The rows may be from 27 to 36 inches apart, and the seed pieces dropped from 12 to 18 inches apart in the rows. Where blight is prevalent, the greater distances are desirable unless thorough spraying is to be carried out. Allowing ample distance between plants obviates the appearance of drawn, weak growths, which are undesirable, particularly because they are most prone to disease. The seed should be set about 5 inches deep in ordinary potato soil. In heavier soils a slightly less depth may be adopted. On large areas machines known as potato planters are used.

Late blight disease (see Chapter 23) is controlled by spraying with Bordeaux mixture or with copper oxychloride.

SUBSEQUENT CULTIVATION

Cultivation should be attended to before the crop is up. The ground is left rough at planting time, a week or ten days later it is harrowed, which breaks the crust and kills a great many weeds. It should be harrowed again when a few plants have made their appearance. As soon as the plants have grown sufficiently to indicate the rows they should be regularly surface cultivated between the rows. Normally, the surface cultivation should be repeated every fortnight or three weeks till the stalks have so grown as to cover the ground between the rows. Hilling should be accomplished gradually, throwing up the soil a little at each cultivation. A large proportion of the roots are to be found near the surface, and sudden deep cultivation or hilling when the plants are well grown will cut a very great number of these roots at a time when the plants can least afford to suffer injury.

HARVESTING

Early potatoes may be dug as soon as large enough and the skin sufficiently firm to stand handling. For the main crop it is necessary to wait till the haulm or stalk and leaves die, and the tubers come freely from the stem, and have not to be jerked off. At this stage the skins are firm and will not come off easily when rubbed.

Potatoes must be dry when gathered, and stored in a cool, dry place away from light.

If the *potato tuber moth* is likely to have been present, dusting the 'seed' tubers with D.D.T. powder will help to kill the grubs hatched from eggs on the tubers. Potatoes for eating should not be treated with D.D.T. To prevent sprouting, *antisprout hormone* powder may also be dusted over the 'seed' tubers while they are being stored.

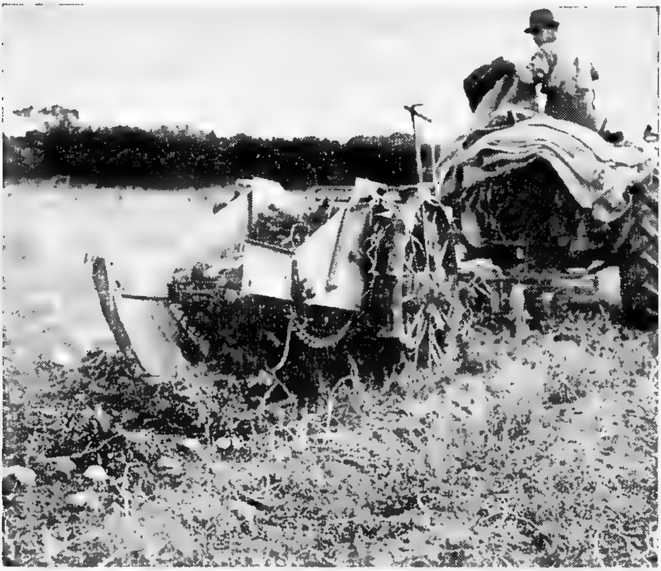


FIG. 98. A potato digger at work

ROTATION

If diseases are very prevalent, cropping should be so arranged that potatoes will not be grown on the same ground more frequently than once in five or six years. Canterbury is the most important potato-growing district in New Zealand, and here the great bulk of the potato crop follows grass. There is some evidence that potatoes grown after a green manure crop of blue lupins are less subject to blight than after other crops. Similarly, where *eelworm* is prevalent, growing turnips or swedes before potatoes helps to control the pest.

VARIETIES

Certain varieties are better adapted to certain soil and climatic conditions than others, and only by trial or by observing other crops in the locality will it be found possible to determine which should be grown.

THE LEGUME FAMILY

NATURAL ORDER: *Leguminosae*

IMPORTANCE OF LEGUMES

The great economic importance of this order is due to—

1. Their ability to make use of the nitrogen in the soil air (see Chapter 12).

2. Their high protein content—a most important constituent of food for animals and man.

PEAS

Peas belong to the species *Pisum sativum* which can be divided into a number of sub-species. Of these sub-species only two are of importance to cultivators, namely *Pisum sativum hortense*—the supposed progenitor of the garden pea and *Pisum sativum arvense* from which field peas are supposed to have evolved.

Most garden varieties have characteristically wrinkled seed coats due to the incomplete conversion of sugar to starch. They are grown for consumption as fresh green peas and also for the quick-freeze and canning trades. A large area in New Zealand is also grown under contract with merchants, for the production of seed peas which are exported.

Field peas have either smooth seed coats or are slightly dimpled, and some varieties, as for example Partridge, have a coloured seed coat, a condition always associated with coloured flowers. Partridge is the main variety grown for stock food and is used extensively in the production of split peas. Blue Prussians are grown for use as boiling peas although perhaps the most popular variety for this purpose is a dimpled Marrowfat type such as Harrison's Glory. Quick-freeze processing is rapidly replacing the canning of peas.

LUCERNE OR ALFALFA (*Medicago sativa*)

Once established, lucerne forms perhaps the most valuable green fodder and hay crop on a farm, giving good yields over a period of 5 to 15 years or more. It produces a number of surface roots and a strongly developed taproot which penetrates deeper into the soil than any other farm crop and is thus able to withstand drought by drawing upon the supplies of moisture in the subsoil. After repeated cutting the stem develops a wide spreading crown from which arise new stems after every cutting.

SOIL AND CLIMATE

The heaviest yields are obtained from deep, friable, rich, well drained soils. It will not grow successfully on poorly drained soils, but with this exception, it is never safe to predict that lucerne will not grow on any soil before it has been given a fair and satisfactory trial. Few crops respond more readily to irrigation and exceptionally good crops are grown by this means in dry, hot climates.

PREPARATION OF THE SEED-BED

Since lucerne seed is relatively small, the seed must be sown at a uniform depth and not too deeply so a fine, firm seed-bed is necessary. To obtain this a liberal amount of preparatory cultivation, commenced well ahead of the time of seed-sowing, must be carried out. As lucerne is very prone to be smothered by weeds, especially during establishment, it is most important that cultivation be such that a weed free seed-bed is assured. (See Chapter 15.)

LIMING

It is safe to assume, unless there is definite evidence to the contrary, that profitable returns will be obtained from liming. Central Otago is an exception to this rule. Lime may be applied with advantage before the final cultivation preceding seed-sowing.

SOWING THE SEED

To secure the required firmness of seed-bed the land should as a rule be rolled prior to seeding. Best results are generally obtained by sowing during the latter part of November or in December.

Over wide areas good results are obtained by sowing the seed at the rate of 12 lb. to 18 lb. per acre, through every coulter of a grain drill to a depth of about 1 in. Broadcasting may also give good results, but calls for the use of a slightly larger amount of seed which is lightly harrowed in.

The Marlborough strain of lucerne is generally to be recommended.

Grazing strains of lucerne are being developed from creeping lucerne (*Medicago glutinosa*), rhizoma lucerne (*M. media*) and Siberian lucerne (*M. falcata*).

INOCULATION

Many of the past complete or partial failures with lucerne are now known to have been due to absence from the soil of the appropriate strain of nodule bacteria (*Rhizobium*).

The safest course is inoculation. Supplies of the necessary organism are called 'cultures', and are obtainable at a small cost. When inoculated seed is mixed with any soluble fertilisers, e.g. superphosphate, sulphate of ammonia, and sulphate of potash, the inoculating organisms on the surface of the seeds are destroyed and nodules do not develop. Also the germination of the seed may be impaired. Inoculated seed must be kept away from direct sunlight.

In many districts it has become the practice of successful growers of lucerne to apply 2 to 4 cwt. of phosphate at or about the time of sowing the seed. In most districts it is very advisable to dress lucerne at least annually with 2 to 3 cwt. of superphosphate, which is at times successfully replaced by basic slag in the

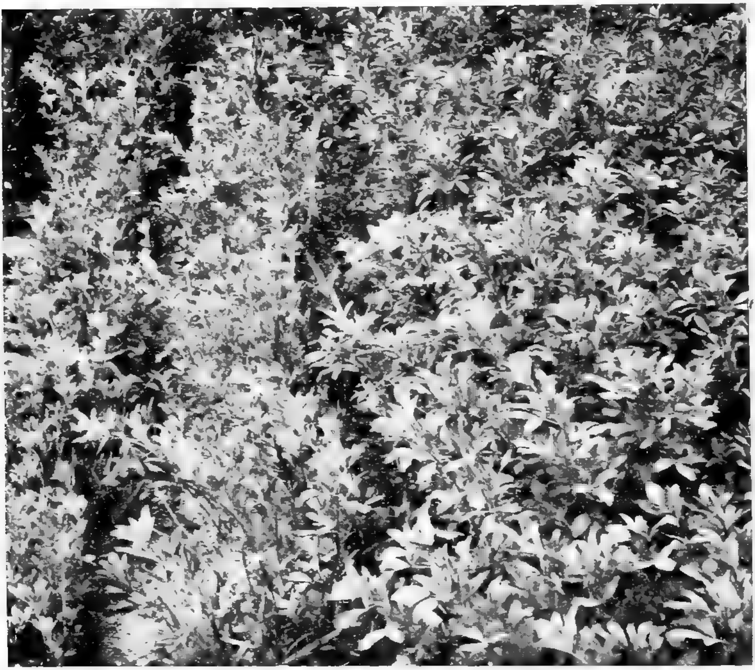


FIG. 99. View of lucerne trial, illustrating benefit of soil inoculation. On left, two rows not inoculated; on right, rows inoculated. Trial at Plant Research Station, Palmerston North

wetter climates. The manurial dressing may be applied with good results as soon as the lucerne has definitely made appreciable new season's growth, or after the first cut of the season has been removed.

TREATMENT DURING FIRST YEAR

The practice that should be adopted during the first year will vary greatly with circumstances. If annual weeds such as fat-hen and thistles have developed rapidly, and threaten by their competition to weaken or even destroy the young seedlings, then it will probably be necessary to mow the crop when it is only a few inches high in order to give the invading weeds a set-back. But if weeds are not threatening to give trouble it is harmful to mow the young plants until they are blooming or fresh young shoots have appeared at the bases of the plants. Delaying the first mowing until this stage favours the growth of an extensive root-system.

MANAGEMENT OF ESTABLISHED LUCERNE

When the new growth coming from the crowns is approximately 2 in. high, which frequently will be the case about September, the vegetation that has been standing during the winter may be removed by mowing, which should be adjusted so as to leave 3 to 4 in. of stubble.

Generally, the new growth, which should be allowed to grow unchecked, provides a cut towards the latter part of November. Partly because the weather usually prevailing at this period is unfavourable to haymaking, the first cut of lucerne is frequently converted into silage.

If lucerne is mown in November, as suggested, it should again be at a stage suitable for mowing early in January. The time and number of subsequent cuts will be determined principally by the rate of growth of the crop. Mowing should be done only at a particular stage of development of the herbage. This stage is reached when new shoots are just starting from the crowns or bases of a considerable number of the plants. Usually when fresh shoots have so developed about a quarter of the plants will be in the early flowering condition.

If the herbage is cut too late feed of unnecessarily low nutritive value is obtained—it is unduly fibrous, and the proportion of leafage as distinct from stems is small. This is of importance, as the leaves are the most nourishing portion of the crop.

Cutting lucerne at an immature stage provides highly nutritious herbage, but, if persisted in, rapidly leads to a weakened stand of decreased production.

CULTIVATION

Principally as a means of reducing the competition of weeds, cultivation of lucerne is at times well worth while. The implement employed should be fitted with tines designed for lucerne cultivation, and dry summer or autumn conditions should be chosen for the work.

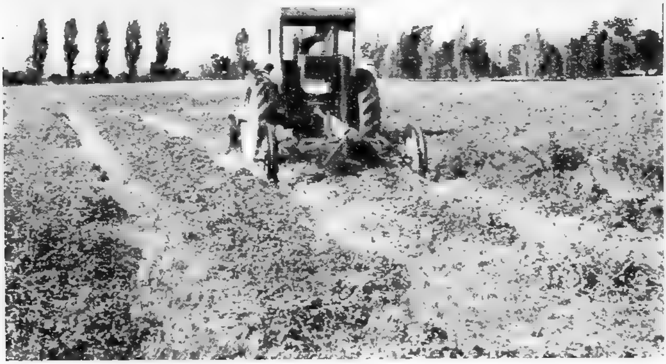


FIG. 100. Cutting lucerne for hay
(*N.Z. Journal of Agriculture*)

HARVESTING LUCERNE

The highest production may be expected from lucerne when it is treated as a hay, silage or green crop to be cut and carted out to stock during late summer, when the growth of pastures is slow. Where it can be grown successfully on dairy farms, it could replace much of the pasture cut for hay and silage. Lucerne thrives under haying, as pasture it deteriorates.

To secure for lucerne a long life of maximum production grazing as a rule should be avoided. Careful grazing of vigorous lucerne may not do much harm to established fields, but grazing of lucerne in its first year, close and continuous summer grazing, and particularly close grazing during the winter period are prone to cause serious injury.

On light, dry land lucerne may be grazed successfully provided that the grazing is carefully controlled, particularly avoiding close, continuous grazing. Cocksfoot combines well with lucerne for grazing pastures, a suitable seeding mixture being 2 lb. cocksfoot to 10 lb. lucerne.

LUPINS, Genus *Lupinus*

The lupin family is used as a green manure and fodder crop. The *Blue Lupin*—the bitter variety containing an alkaloid—is used in many parts of the country as a fodder crop sometimes replacing the turnip crop as a winter and early spring feed. More recently a sweet variety has been imported which is very palatable to stock and is now being used in conjunction with rape and sometimes by itself for lamb-fattening purposes for which it is eminently suitable. There are two varieties of *sweet lupin,* the *sweet blue* and the *sweet yellow.* In the past sweet lupins have not been popular owing to erratic seed yields, poor vigour and hard seed which is slow and irregular in germination. A sweet variety, Borre, introduced in 1948 overcomes all these defects. The species of agricultural value are all annuals and are sown when the danger of frost is over and are either broadcast, or drilled at the rate of 2 to 2½ bushels to the acre in 7 inch drills. Lupins prefer a slightly acid soil and no liming. The *perennial yellow lupin,* so common in New Zealand, is of no food value but proves very useful in reclaiming sand areas providing the sand is not moving rapidly.

MANGELS AND BEETS

NATURAL ORDER: *Chenopodiaceae*

The plants of chief economic value belonging to the natural order Chenopodiaceae are mangels and beet.

The flowers of the order are small and greenish. Cross-pollination is made necessary by the fact that the pollen ripens before the stigma is mature. The pollination is effected probably by both insects and wind.

The root system is extensive, and often penetrates to great depths. A cross section of the root shows a series of concentric rings of firm tissue separated from one another by rings of softer tissue. This peculiar arrangement is the result of the presence of several rings of cambium tissue, each of which produces woody tissue and soft tissue (bast).

MANGELS (*Beta vulgaris*)

The mangel was one of the most valuable root crops but its popularity has waned.

SUGAR BEET (*Beta vulgaris,* var. *saccarifera*)

In Europe sugar beet is used extensively for producing common sugar, the waste products of the process being used for stock feed. Sugar beets are also grown for feeding to livestock.

FODDER BEET

Numerous varieties of fodder beet, the result of cross-breeding mangel and sugar beet, are becoming extremely popular. A good strain or variety of fodder beet has a high dry matter content (17 per cent to 19 per cent); like mangels, more than half the root grows above ground level, facilitating harvesting; it can be fed immediately after pulling or fed off *in situ,* thus saving much time and labour; it is a very suitable feed for pigs during winter.

CARROT AND PARSNIP FAMILY

NATURAL ORDER: *Umbelliferae*

The flowers are borne in umbels or compound umbels. An umbel is a collection of flowers with stalks which are of similar length and which spring from the same point on the main flowering stem, with the result that the flowers are massed together in clusters with even surfaces and with the youngest flowers in the centre. In compound umbels there is double branching, and the clusters, which are themselves simple umbels, are arranged in the form of umbels. The flowers are generally pollinated by small insects. The stamens often set free their pollen before the styles of the same flower are mature enough to receive it—hence cross-fertilisation results. The fruit is a schizocarp, i.e. united carpels (two in this order) which are separate from each other but which do not set free the seeds they contain. Commercial seeds are not true seeds, i.e. mature ovaries, but are mature carpels.

The farm crops of the order are the carrot and the parsnip. The garden crops, celery, parsley, and caraway, also belong to the order.

THE CARROT (*Daucus carota*)

SOIL

A deep, well-pulverised, sandy loam with free subsoil provides the ideal conditions, giving scope for the development of the deep root system which characterises this crop. Stiff or shallow soils are unsuited, shallowness causing forking of the roots. However, some varieties are naturally short and thick, and these should be utilised for shallow soils. It is highly desirable that the soil be free from weeds and weed seeds, because the young plants with their narrow leaves are ill-fitted in the struggle with vigorous annual weeds. Carrots may successfully follow grass or rape, both of which leave the soil in a comparatively clean state.

USE

With the exception of parsnips and potatoes, carrots contain more nutritious matter per ton than any other root crop. They are relished by cattle, sheep, and particularly by horses, on which they rapidly produce the bloom or sleekness so essential for show purposes. Their succulence and juices possess a dietary value and tone up the system of stock.

The crop, apart from the Guerande variety, is usually harvested by hand pulling and topping—this work can be facilitated by running a plough along both sides of the row. The crop should be left in the ground as long as possible. When pulled the roots should be stored in pits like potatoes, or kept in dry sand. Some varieties, with a large proportion of their roots above ground level, are easily harvested.

FLAX AND LINSEED

NATURAL ORDER: *Linaceae*

The Linaceae comprises a small order of which the genus Linum is the most important. Some of the species are cultivated in the garden on account of the brilliant colours of their flowers but the important commercial species is the annual linseed or flax (*Linum usitatissimum*).

The upper part of the plant is branched bearing a single flower on each terminal. There are five each of sepals, petals, stamens, and styles. The ovary is also five-celled, each cell being divided into two thus making ten, in each of which a seed may develop. The capsule or 'boll' splits longitudinally when ripe, setting free the ten seeds within.

The plant is grown commercially for two purposes, namely, for seed from which linseed oil is extracted, and for fibre from which linen is manufactured. While botanically the same, those varieties grown for seed are short and branched having been selected to produce a heavy yield of seed (about 10 cwt. per acre) of high oil content (38 per cent to 42 per cent). Those varieties selected for fibre production are tall and slender, producing little seed, but containing a higher content of fine quality fibre than in the case of the linseed varieties.

LINSEED

The crop grows well on land suited for wheat. It is normally sown in the spring at the rate of 35-45 lb. of seed per acre by means of the ordinary grain drill. Sown in October it would be ready for harvesting in February or March.

One extracting plant operating in Dunedin deals with all the linseed grown in New Zealand. The seed is crushed and the oil extracted while the residue forms a valuable stock-food concentrate known as linseed oil cake.

LINEN FLAX

Commercial linen flax is comprised of the bast fibres of the plant. As seen in a cross section of the stem the fibres occur in about thirty bundles each containing about thirty fibres arranged in a ring just under the surface of the stem.

Flax for fibre production is highly selective in its soil requirements because to produce satisfactory yields of high quality fibre the plant must grow evenly without any check as may be occasioned by a dry spell. An even moisture supply is therefore essential but soils need not be highly fertile as this might lead to rank growth containing a low content of coarse fibre.

NATURAL ORDER: *Cucurbitaceae*

Agricultural plants of importance in this order are pumpkins, squashes, marrows, cucumbers, and the various kinds of melons. The plants have two types of flowers and are cross-pollinated by insects. The various members of the order cross-pollinate with one another quite readily, and, therefore, should not be grown close together if seed is to be saved.

PUMPKINS AND SQUASHES are grown for feeding to stock in climates where maize can be successfully grown. They are in fact frequently grown with the maize crop, but the practice is not to be generally recommended on account of the difficulty in cultivating the maize.

PLANTING

When sown alone drills are run out from 9 ft. to 12 ft. apart, and 5 or 6 seeds dropped almost together at intervals of about 5 ft. or 6 ft. They are later thinned out leaving 2 plants in each 'hill'. About 2 pounds of seed is sufficient for 1 acre.

The table pumpkin differs from the cattle pumpkin in being smaller, less coarse in the flesh, and the seed cavity is smaller in proportion to the size of the pumpkin.

NATURAL ORDER: *Compositae*

Plants of agricultural importance in this order include Jerusalem artichokes, sunflower, and lettuce.

JERUSALEM ARTICHOKES (*Helianthus tuberosus*)

This crop is grown for the tubers which are potato-like in appearance, and which may be white, yellow, or red in colour. They are to some extent used for table purposes, and to a small extent for stock, chiefly pigs. The main carbohydrate is inulin and not starch.

DEMONSTRATION PLOTS OF FARM CROPS

Exercise 1.—Prepare demonstration plots of the chief kinds of farm crops. A suitable minimum area would be of rectangular shape, 15 ft. by 30 ft. After proper cultivation, fertilise and sow the area in the spring, placing the fertiliser in a band just below the seed. The sowing should be done at the depth, rate of seeding and distance between the rows appropriate to each crop.

Suggestions for observations:—

(1) Seedling emergence and development of the various crops, comparing their forms and rates of growth. Both root and shoot should be considered.

(2) Thin the seedlings at the stage of growth proper to each crop, leaving a portion of each row unthinned. Try to transplant a few seedlings of each kind removed during the thinning.

(3) Treat a portion of each of the rows of young cereals differentially in ways such as the following: (a) Defoliated once from 9 in. high to 3 in. high. (b) Treated with weedkiller at the proper stages of growth. (c) Given a side dressing of sulphate of ammonia at ½ oz. per 10 ft. row or at ½ oz. to a gallon of water per 10 ft. row.

(4) Treat with the side dressing some of each row of the other crops.

(5) Compare the varieties and species in the young vegetative stage for the purpose of identification.

(6) In February and subsequent months compare the varieties and the species for identification at or near maturity.

(7) Note when the various crops reach maturity, and, if livestock are available, feed out each crop when it is mature.

READING

Arable Farm Crops of New Zealand, Hadfield, J. W.

Agricultural Botany, Yeates and Campbell

Farming in New Zealand, N.Z. Dept. of Agric.

Primary Production in New Zealand, N.Z. Dept. of Agric.

N.Z. Journal of Agriculture, 'Cereals'; Apr. 1958, June 1956, Feb. 1955, July 1950. 'Roots'; Oct. 1957, June 1955, Sept. 1955, Oct. 1953. 'Potatoes'; Mar. 1955, Apr. 1953

Canterbury Chamber of Commerce Agric. Bull., Nos. 317, 277, 334, 315, 333

20

Conservation of Fodder

PASTURE constitutes the main fodder conserved in New Zealand, about 500,000 acres being cut annually for hay and about 150,000 acres for silage. Lucerne comes next with about 90,000 acres cut for hay and silage. As we noted in Chapter 18, well-managed pasture is the best and cheapest of animal feeds. Owing, however, to seasonal variation in pasture production, the surplus at one time of the year has to be conserved for stock feeding at another time when pasture production is low. (Refer to the graphical diagram in Chapter 18.)

The relatively small surplus of pasture in the autumn is winter stored and grazed in the spring. The far greater surplus which occurs in the late spring is conserved in two ways, by ensiling and by haymaking. In some overseas countries there is a third method, oven-drying of cut herbage. Oven-dried pasture retains a higher proportion of digestible nutrients than does hay or silage, but is much more expensive to produce. Except under the most favourable conditions haymaking is the most wasteful method of conservation. The unsettled weather general in New Zealand often causes large losses of nutrients during haymaking. Ensiling on the other hand can proceed with much less regard for the weather and can be controlled fairly closely. With the advent of labour-saving devices, notably the buckrake about the year 1950, ensiling became revolutionised. Instead of the slow, laborious process it used to be, it is now one which can be carried out quickly and with few men.

Pasture conservation is of the greatest importance where dairying is carried out, but sheep farms, especially those which carry a high proportion of cattle, can make good use during lean periods of the stored surplus pasture growth of the spring.

HAYMAKING

Usually the vegetation used for hay consists of a mixture of several different kinds of plants—grasses and clovers; sometimes only one kind of plant is present, e.g., lucerne, red clover, ryegrass. In each case there are advantages and disadvantages.

The mixed hay will probably be a better-balanced food but it is almost certain that some of the plants will be mown either too early or too late. The mixed hay is also more difficult to cure, because of the variation in coarseness and moisture content of the different kinds of plants.

Before closing a paddock for hay it should be harrowed to spread stock droppings and to reveal any pieces of wire or similar rubbish which may cause trouble in harvesting.

TIME TO CUT

Both the quantity and the quality of the yield must be taken into consideration when the field consists of a mixture of plants. The best time to cut is when the majority of the plants are in the early flowering stage, that is to say, in the case of grasses when the anthers are protruding. At this stage the weight of herbage is not at its maximum but is nearly so, and the difference in this respect is more than counterbalanced by the improvement which results in its nutritive and digestive properties. The general rule is that, as plants pass from the flowering stage to the ripe stage, the stems become hard and indigestible and much of the nutritive material becomes transferred to the seeds which are easily lost from the hay. It is of course preferable to have this nutritive material distributed through the stalks and leaves.

Clover should be cut at full bloom. It is then less fibrous than when mature. Though the yield is slightly smaller than that secured at maturity, yet the crop contains the maximum amount both of proteins, which are especially valuable, and of essential or characteristic oils, which impart palatability. Further, at the full-bloom stage the nutrients are more thoroughly distributed and more easily digested.

Lucerne for hay should be cut just when young shoots have started from the crowns. This usually occurs in the early flowering stage, when about one-tenth in bloom. Not only does this give the best quality hay, but it also fosters a more vigorous and immediate subsequent growth, because the cutting takes place before the young shoots have grown sufficiently to be mutilated by the mower, and because they have not been weakened by excessive shade.

If the grass consists of a single species, say ryegrass, it is usually not difficult to determine the most suitable time to cut. In the case of plants like cocksfoot, which become fibrous and lose their palatability earlier than others, cutting should take place before the flower heads are well out of their sheath. This applies when such plants are sown alone and when they form the main constituent of the hay. It is preferable, when other conditions permit, to mow just after a period of dry weather, for the process of curing is thereby facilitated since the material contains somewhat less moisture and it dries more rapidly.

The important point is to cut at the proper stage of growth, both because of the superior feeding properties of the crop and the greater and better subsequent growth or aftermath.

In a hay paddock the tall-growing species like cocksfoot tend to shade low-growing species like ryegrass and white clover and these latter species become suppressed. Consequently pasture production in the following autumn and winter becomes reduced. With the recovery of the ryegrass and white clover, pasture production returns to a high level. Where, however, the hay harvesting is long delayed or where a paddock is shut up for two or more years in succession, this recovery is slow or impossible and the sward shows succession to low-producing species.

CURING

In making the hay much depends on the weather conditions. In general, the less the hay is turned and tossed about the better, for the bruising and breaking of the stems and leaves which results from handling tends to destroy the protective coating of the grass stems and facilitates the entrance of water and the process of decay. Consequently in continued wet weather it is well to leave the cut grass undisturbed when it will suffer the minimum of harm. Further, the handling of the vegetation causes loss through the dropping off of leaves, particularly those of clover and lucerne, and the leaves being the most valuable portion, everything possible should be done to preserve them. Hence in turning clover and lucerne hay the swath-turner is preferable to the tedder because the gentler action of the former gives rise to less waste of leafage.

Given good weather, pasture cut in the morning or the afternoon should be turned after half a day in the swath and turned again 24 hours later. Soon afterwards the hay is ready for cocking, or baling or stacking.

In hot, dry weather grass may often be put into windrows the day it is cut. If wet weather threatens it is advisable to put the crop into small ‘cocks’, even if it is not in first-rate order.

When the weather improves the cocks must be shaken up to dry. The advantage of the cocks arises from the washing action of rain. One inch of rainfall is equal to 101 tons of water per acre. If the crop is evenly spread over the field it is subject to the washing influence of the greater portion of this water; if, however, it is in cocks that occupy only one-twelfth of the area it is subjected to only one-twelfth of the rainfall. The water not only washes out a considerable amount of the readily-digestible nutrient material but also removes the appetising aroma from the crop.

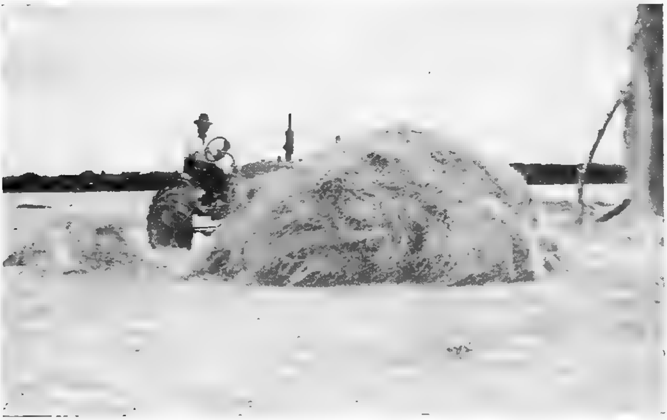


FIG. 101. Tractor sweeping hay and showing mower bar attached behind ready for further cutting when sweeping is completed. A mid-mounted mower is more easily controlled than one rear-mounted (*N.Z. Dept. of Agriculture*)

Only experience enables one to determine when hay is fit to be stacked or baled. A reliable test is to twist a handful of stems tightly into a rope. If the pressure causes moisture to appear the material is not fit for stacking. In fine weather luxuriant growth is somewhat liable to be carried in prematurely, for the leaves and finer shoots dry quickly and give the bulk of the material the desired appearance before the succulent stems have lost sufficient moisture.

STACKING

In making a hayrick or stack the first thing to attend to is the foundation. A high well-drained site should be chosen and it should be in a position convenient for distribution later on. The material should not be placed on the bare ground, for wastage would certainly result near the damp ground. A foundation of straw or preferably of logs should be constructed to check the absorption of moisture from the soil; the logs allow of bottom ventilation which makes it safe to put material into the stack earlier than would be otherwise safe.

A square-shaped or a round stack is best, giving in proportion to the cubic content the minimum of surface at which a certain amount of waste is unavoidable. The area of the bottom of the stack should be smaller than that at eaves to allow rainwater running off the roof to fall on the ground rather than down the sides of the stack.

The material in the stack should be well and evenly consolidated by careful trampling, the object of this being to regulate the amount of fermentation, for over-fermentation which results from loose stacking produces a dark hay of inferior value.

Hay which has deteriorated through unfavourable weather conditions such as successive soakings and dryings, will be improved in quality and palatability by the addition of salt sprinkled over each layer at the stacking time at the rate of 15 lb. of salt to each ton of crop.

USES

Besides providing a maintenance ration for dry stock during the winter, hay gives bulk to satisfy the appetite in rations containing foods rich in digestible nutrients such as youthful pasture and watery foods such as roots. Hay is similarly useful in offsetting watery pasture commonly occurring during the flush of spring growth. Provided hay contains no appreciable amount of clover, it can be used to help to avoid bloat in cattle. For sheep, shut up against facial eczema, hay is a good feed for maintaining condition.

Exercise 1.—(i) Given a hay crop estimated at two tons per acre in a paddock of 6 acres, find from tables, (a) how many round hay stacks each 5 yd. in diameter would be required; (b) what length and breadth for an oblong hay stack, twice as long as broad, should be decided upon to hold all of the hay crop. (For tables, see *N.Z. Dept. of Agric. Bulletin,* No. 290, p. 29.)

(ii) Given the density of hay as 8 lb. per cu. ft., calculate the weight of the hay in (a) a round stack with 12 ft. mid-diameter of the butt, 5 ft. high to the eave and 6 ft. high from eave to peak; (b) an oblong stack with average length and breadth 32 ft. and 16 ft. respectively, height 9 ft. to the eaves and 8 ft. eaves to ridge.

SILAGE

The term ensiling is applied to the process of fodder conservation in which the crops are harvested while green and succulent, and immediately or soon after cutting are either stacked or stored in a pit or silo. As a result of storing the material in this state, strong fermentation is set up and the temperature rises rapidly. By increasing the pressure, and thus excluding the air, the fermentation and rise in temperature can be reduced. The resulting silage is yellowish green to dark brown in colour.

Changes Which Occur in Silage

Soon after the green material is stored there is a rise in temperature. This is due at first to the breathing of the plant cells in which carbohydrate is oxidised to carbon dioxide and water with generation of heat which cannot readily escape from the compacted material. When the supply of oxygen in the entangled air is used up, the breathing of the plant cells stops and fermentation, an incomplete type of oxidation, sets in. Sugars, instead of being turned into carbon dioxide and water, are turned into organic acids chiefly acetic, lactic and butyric acids. Proteolytic enzymes act on the proteins turning them into amino acids. These chemical changes contribute also to the rise in temperature of the stored material. As the acidity develops the chemical changes slow down and then stop so that the temperature gradually falls. The acid preserves the silage.

As the most desirable natural preservative for silage, from the viewpoints of palatability and retention of nutrients, is lactic acid, the process should be directed as far as possible towards the kind of fermentation in which lactic acid is produced. To this end the crop is cut at the best stage of growth (see the next section), given tight packing, is wilted before storage if the crop is immature or is wet, and the storage structure filled intermittently.

Immature crops are usually not rich enough in carbohydrate in proportion to protein for lactic acid fermentation to proceed adequately. By adding molasses to the immature crop at the rate of 20 lb. per ton, enough sugar is made available to produce the amount of lactic acid necessary for preserving the fodder.

A useful artificial preservative for ensiling protein-rich fodder is sodium metabisulphite applied at the rate of 8 to 10 lb. per ton. It acts by reducing the oxygen content of the air entangled in the stored material, and also by producing the gas, sulphur dioxide. This gas appears to kill or prevent the action of undesirable bacteria and fungi which produce butyric acid and those which cause the breakdown of valuable protein while allowing lactic acid bacteria to produce some lactic acid. If the bisulphite is mixed uniformly throughout the ensiled material which has been cut at the best stage of growth then a high quality silage should result.

During ensiling the material loses some of its feed value because of the oxidation process, and at times because of the escape of juice containing soluble nutritive substances, and again at times because of a reduction in digestibility, which occurs most markedly when the higher temperatures are reached.

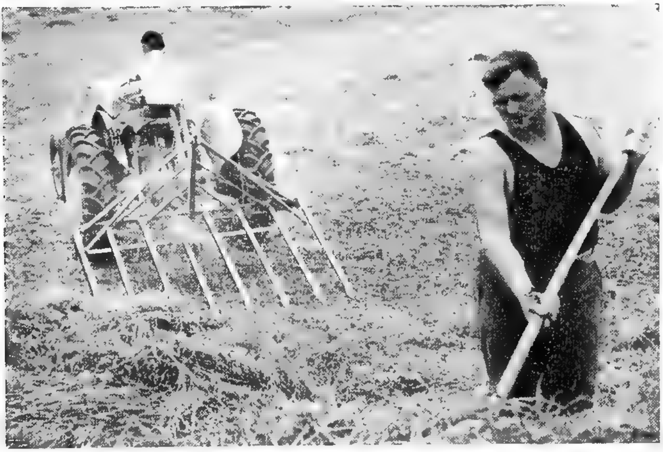


FIG. 102. Buckrake coming off wedge stack and travelling out to load up (*N.Z. Dept. of Agriculture*)

CROPS SUITABLE FOR ENSILAGE

Almost any class of fodder crops, roots excepted, can be made into silage. Good pasture growth, of grasses and clovers mixed, mown when at the early flowering stage, is excellent. Most of the cereals, such as oats, maize, millet, either grown by themselves or in conjunction with peas or tares, provide high-class silage. Lucerne makes good silage, but mixing lucerne with grass or a cereal such as oats or maize, usually gives a still better silage. However, the lucerne crop, apart from the first cut of the season which is usually fit to be harvested when the weather is unfavourable for haymaking, and which is also usually infested heavily with weeds, is generally most profitably utilised for hay or green feed.

The quality of silage is determined to a considerable extent by the stage of growth at which the crops forming it are cut. Swards consisting of a mixture of pasture species should be mown when the predominating kinds are in the early flowering stage. Maize is generally cut when the cobs are taking on a glazed appearance; other cereals when the grain is changing from the milk to the dough stage; peas and tares between the blooming and early podding stages. If green material for ensilage has been allowed to become too mature the silage it yields is of lowered feeding value, and in the case of pasture growth the likelihood of securing a good aftermath on the mowed field will have been decreased.

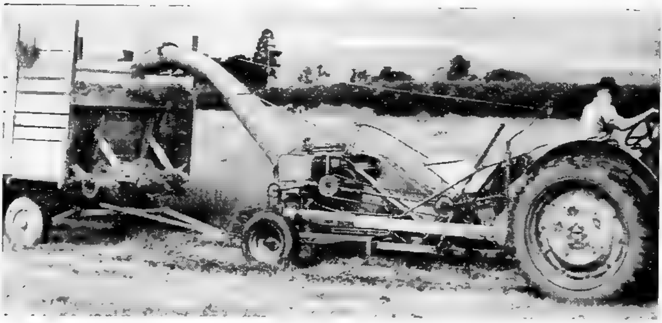


FIG. 103. Forage harvester cutting pasture and blowing chopped material into a trailer (*N.Z. Dept. of Agriculture*)

ENSILING METHODS

There are four main ensiling methods:—(1) the overground silo, (2) the pit and the trench, (3) the clamp, (4) the stack.

THE SILO

Where stock are housed and fed indoors in winter the silo is common, its use being linked with that of a cutter and blower for satisfactorily filling. Under such conditions it is a convenient means of storing silage with small wastage of material. Under New Zealand conditions the initial cost of the silo is viewed seriously, particularly as it is not counter-balanced by considerations of convenience, which apply to the feeding of housed stock. The silo may lead, for the sake of convenience, to the repeated mowing of pasture in its neighbourhood—a practice which is likely to result in deterioration of these pastures. As fully-efficient silos must be airtight it follows that cheap and portable ones usually are unsatisfactory.

THE PIT AND THE TRENCH

The pit and the trench methods are essentially alike, the pit being a deeper excavation than the trench. Since much air can be excluded by consolidation against the walls these structures avoid side wastage of the silage so prominent in stacks where it commonly occurs inwards about a foot. Pits and trenches are suited only to well-drained country. Because of its greater depth the pit is most suitably located on a bank or terrace in a manner which allows of the weighty green material being filled in at the top and carted out from the lower side. Pits should be round and trenches rounded at the corners so as to enable air to be excluded as far as possible from the stored material. Because of their fixed situations pits and trenches may cause paddocks nearby to be used for silage too frequently resulting in pasture deterioration as in the case of the silo. This defect may be overcome to some extent by so locating the pits or trenches that several fields may conveniently be utilised in the filling of them and used for silage in rotation. Well-constructed pits and trenches are usually much cheaper than silos, and practically eliminate wastage of material.

THE CLAMP

Introduction of the buckrake led to the invention of new types of silage stacks, collectively referred to as clamps. Taking one of several forms, chiefly buns and wedges, a clamp allows the buckrake with its load gathered when the tractor moves in reverse along a swath, to discharge on the stack without stopping. As the tractor passes over the stack, material already deposited and evenly spread is consolidated. Time must be allowed for heat to develop in the consolidated material before adding more, otherwise sour silage will be formed. To avoid waste of time two clamps may be used, being added to alternately. The same applies to trenches.

The *bun clamp* is simply a heap of grass shaped like an inverted saucer. It has the great advantage that the tractor may be driven over all of its surface in all directions giving good consolidation. With the ordinary *wedge clamp* consolidation right out to the edges is impossible without endangering the tractor and driver. By providing portable walls for the clamp this danger may be removed. Such a clamp has the advantage a trench has in achieving good consolidation of the sides, and hence little wastage, with the added advantages of greater ease in removing the silage for feeding and of avoiding a fixed situation. Disadvantages of the bun clamp lie mainly in its large surface area necessitating very even consolidation and an even surface with very careful sealing if large wastage is to be avoided. It also takes up much space and must be well away from the sides of the paddock.

Just as the buckrake excels for ensiling on small farms so does the forage harvester excel on large farms, especially with the trench method. The latter machine cuts the crop, sucks up the cut material, chops it up, and then blows it into a towed trailer.

THE STACK

Stacks are very convenient since they may be located on the site most handy for the crop to be handled. It calls for no direct outlay, but it is markedly laborious. More wastage of material occurs in the stack method than in other methods.

SEALING

The stored green crop requires to be sealed without much delay. With clamps, pits and trenches sufficient consolidation has been produced, so that it is only necessary to roll the surface with a tractor to produce a mush which acts as a seal. With ordinary stacks, however, pressure must be applied also and earth is the most suitable material for this purpose. If the silage material is hot and settling quickly the covering should be put on as soon as the material has been gathered, and usually it should be put on within a day. The covering serves not only to prevent rainwater from penetrating the silage and leading to its decay, but also to exclude air from the top layer of silage by pressure, and thereby to regulate its quality and secure its preservation. If pressure is not exerted completely over the silage right out to the wall avoidable wastage will occur. Hence it is advisable to use a frame of some sort to hold the covering of earth on the top near the wall. Sawn timber and netting wire often are used effectively for this purpose.

The covering of earth should vary in depth from 15 to 18 inches at the centre of the covering to 9 to 12 inches along the sides. In dry conditions deeper coverings are usually advisable.

ADVANTAGES OF ENSILING OVER HAYMAKING

There are several advantages attaching to ensiling apart from its great service as a means of building up feed reserves from surplus pasture growth. Ensiling is often markedly more serviceable and suitable than haymaking after making full allowance for the fact that ensiling involves dealing with a much greater weight of material than does haymaking. Ensiling is superior to haymaking under many circumstances primarily because it allows of surplus feed to be dealt with when it is at its most nutritive stage. This is because silage can be made irrespective of the weather conditions which so often either delay haymaking or result in the loss or deterioration of the crop before it is saved as hay. Conserving surplus growth when it should be done, rather than when the weather permits it to be done, is beneficial in three distinct ways. In the first place the conserved material is of greater feeding value, in that there is no reason for it to be characterised by the excessive stemminess and consequent poor digestibility that characterises much of the hay that is made. In the second place the farmer is enabled to avoid the excessively busy periods of work which are a feature of haymaking, and which often lead to costly neglect of other important farm work. In the third place the pastures benefit in a dual manner when surplus growth is removed at the right time. No rank growth, with its consequent harmful suppression of useful species such as ryegrass and white clover, and a better and more reliable aftermath can be expected when the surplus growth is removed at a suitably early stage.

A further advantage of ensiling is that it gives reserves of feed which are practically free from damage from vermin and from fire risk. In addition ensiling can at times be resorted to in order to hold in reserve crops that could be dealt with satisfactorily in no other manner. For instance, the first cut from a lucerne area ordinarily becomes available each season at a time when conditions are extremely unfavourable for haymaking, and when there is nothing to be gained by giving the stock green feed in addition to that which is obtainable from the fields under grazing. It is much against good future yields from the lucerne to leave the growth unmown until good haymaking weather can be expected. The only satisfactory course is ensiling. In like manner growth containing heavy quantities of weeds such as thistles can at times be conserved in edible form as ensilage, whereas in the form of hay, stock would not consume it. It must not be inferred, however, that no particular attention need be paid to material intended for ensilage, or that good silage may be made from any kind of material. The process of making silage may, to some extent, disguise the nature of the material of which it is composed, but it does not increase the amount of nutrient in the fodder. Hence it may be accepted as a rule that good silage comes only from good material.

The principal kinds of silage are:—(1) Sweet dark brown, produced at a temperature above about 120° F. (2) Acid, light brown or yellow brown. (3) Green 'fruity'. (4) Sour. (5) Musty. The three latter kinds are produced at temperatures lower than 120° F. The knowledge of the feeding value of the various kinds is incomplete, but in general dark brown silage is inferior in feeding value to greenish or light brown silage, while sour silage is valuable, and musty silage is not, being unpalatable, unwholesome and dangerous.

Quantities in Silage

The weight of a cubic foot of silage commonly varies from 35 to 55 lb.; the average weight may be taken as 45 lb.

An average good crop of mown permanent pasture provides approximately 8 tons of green material an acre; a fairly good crop of lucerne or temporary pasture 7 to 9 tons, and good crops 10 to 12 tons an acre; crops of cereals and tares or peas, 10 to 14 tons; millet, 12 to 16 tons; maize, 30 to 50 tons an acre. The depth of wastage on the walls of a small stack is the same as in the case of a large stack. Hence, as the size of the stack decreases the proportion of wastage increases. Because of this it is not as a rule economical to make stacks from less than 20 tons of green material: this does not apply to other methods of storing in which the wastage is less serious.

Use of Silage

In essential respects silage is similar to the crop from which it is made. Hence it is not surprising to find that it is fed with success to cattle, sheep, and horses. Alone or in conjunction with hay it provides a splendid winter ration and it also proves useful as a succulent food for dairy cows in summer, especially if it has been made from leafy material. A ration of roots and silage is not recommended because of the succulence of both feeds. In general 1 lb. of silage is equal in feeding value to 2 lb. of roots, while 1 lb. of hay is equal in feeding value to 3 lb. of silage. In addition to nutritive value, other matters, such as succulence, should be considered in deciding the use of these feeds.

Exercise 2.—(a) Examine some silage and estimate its quality by appearance and smell. (b) Observe stored silage for features of its site in relation to access, removal of fodder in the winter and drainage. (c) Measure the dimensions of the structure, and, allowing for density of 35 lb. to 55 lb. per cu. ft. according to the probable amount of consolidation, calculate the weight of silage in the structure when full. (d) If dairy cows eat an average of 50 lb. of silage per head per day over a 100-day period of pasture scarcity along with some pasture, how many cows would the amount of silage you calculated in (c) above support for the period?

AUTUMN SAVED PASTURE

After the autumn rains have fallen, pasture which becomes surplus to current requirements should be shut up. To allow the maximum saving of pasture at this time, hay and silage feeding should be started early in the winter. Before being shut up, topdressing the area with the necessary fertilisers and harrowing to spread the animal droppings should have been carried out. It is an advantage if paddocks are shut up in succession so that the winter-stored pasture is available for grazing in succession, and so that no pasture becomes too long in growth. If too long the pasture tends to cause (1) loss of leaf in the bottom by shading and rotting, (2) reduction in palatability and digestibility, (3) suppression of clovers and (4) poor recovery after grazing. To prevent the pasture becoming too long it should be lightly grazed in breaks. In the early spring the winter-stored, high quality feed is break-grazed and carefully rationed. It is specially useful for dairy cows and breeding ewes two or three weeks before parturition and then afterwards until pastures generally have got under way with spring growth. The bulk of the rations will be made up usually with hay and silage.

READING

N.Z. Dept. of Agric. Bulletins, Nos. 290 & 313
Canterbury Chamber of Commerce Agric. Bulletins, Nos. 251 & 252
N.Z. Fertilizer Journal, Mar. 1955
Massey Agric. Coll. Sheepfarming Annual, 1956, (pages 57 & 63)

21

Farm Trees and Shrubs

EVERY farm needs trees and shrubs, some farms much more than others. Not only do trees and shrubs help to protect livestock, crops and soil, but also their products provide amenities for a farm and possibly also, by the sale of timber, a direct source of farm income. Some farmers grow trees as a crop, albeit a long rotation crop of about thirty to fifty years. Tending the tree crop fits in well with the general farming programme, for most attention to the trees and harvesting of their products can be carried out in the winter. There are four main methods of planting trees and shrubs on a farm:—(1) In a nursery. (2) In rows as shelterbelts. (3) In blocks as woodlots. (4) Widely-spaced, singly or in small groups.

Trees and shrubs, while requiring growing conditions similar in most respects to those for herbaceous crops, differ from the latter in the following ways:—

(1) Often having mycorrhiza on the roots (see Chapter 4) they are able to grow successfully in soils low in available nutrients and high in acidity. A woodlot can therefore be sited on the poorer soil of a farm. However this does not mean that any poor land is able to grow trees satisfactorily.

(2) Requiring deep rooting to withstand strong winds they need soils of good depth. If deep soil is not available, then special precautions such as borders of wind-resistant species around a woodlot or on the windward side of a shelterbelt are necessary for protection of the rest of the stand.

SELECTING TREES AND SHRUBS

A useful general rule for selecting trees and shrubs for a farm is to note those which are growing well in the locality and, realising that growing conditions can vary within even short distances, to use those which are suitable for the conditions and the needs of the farm. However new species and varieties should be considered and tried also.

Many are the factors which enter into the suitability of trees and shrubs for a farm. Some of the more important of these are:—height of growth and density of growth especially near the ground; resistance to frosts; soil fertility and soil water requirement; tolerance of a high water-table; ease and speed of establishment, rate of growth and length of life; resistance to wind, including salt-laden wind; resistance to disease; and quality of timber. With trees and shrubs meant for hedges further important factors are:—tolerance of heavy trimming and degree of proof against livestock.

Where winter shelter for livestock is not required and free access of sunlight in the winter is desirable, deciduous trees and shrubs rather than evergreens will be used, as, for example, lone single trees whose main function is to provide summer shade, and a shelterbelt around an orchard. Woodlots of mixed species of two or more evergreens or evergreens with deciduous species, rather than being made up of a single species, may be desirable from the following viewpoints:—

(1) Mixed woodlots are less subject to spread of disease.

(2) If one species is killed by disease, there is another to carry on production.

(3) Because the different species mature at different times, mixed woodlots provide a greater continuity of production.

(4) There is likely to be better soil development. Soil deterioration may occur, for example, in the case of a stand composed only of pines. (See Chapter 8.)

(5) Mixed woodlots usually provide a better home for birds useful in controlling insect pests and for carnivorous and parasitic insects also useful in controlling insect pests.

The main disadvantages of mixed species in a stand, compared with single species, centre around the need to avoid one species smothering another. For shelter the disadvantages are not so serious as for timber. They are:—

(1) More careful planning of the stand is required.

(2) More attention is needed in establishing and maintaining the stand.

(3) In spite of precautions, the quicker growing species may, (a) suppress the slower, and (b) become severely damaged by having their tops broken by strong winds.

ROLE OF TREES AND SHRUBS ON A FARM

Closely concerned with selection is the role of trees and shrubs on a farm, for selection of the species or the variety is determined to some extent by the use to which it is to be put. Trees and shrubs are needed on a farm for:—

(1) sheltering stock and crops against strong wind and strong sunlight; (2) providing timber; (3) preventing soil erosion; (4) providing fodder; (5) smothering weeds; and (6) beautifying.

These uses may be to some extent interdependent but not necessarily so. The provision of timber, especially building timber, for instance requires a woodlot managed specially for timber production, none of the other uses for trees on a farm necessarily coming into play. Similarly a shelterbelt is meant to be in position as long as possible solely for shelter, though the farm may be beautified also by its presence. Any timber produced by a shelterbelt is usually incidental and of poor quality.

TREES AND SHRUBS FOR SHELTER

General protection for stock, crops and soil against strong winds and cold winds, protection of livestock against strong sunlight, shelter of the orchard and the piggery, and shelter of the homestead are the chief needs for shelter on a farm.

A *shelterbelt* is a stand of trees in two or more rows, each row being of a different species from the others. One or two border shrubs or small trees are often included. Features of the ideal form of shelterbelt are:—

(1) Dense and impenetrable near the ground to prevent ground draughts affecting livestock, and slightly penetrable in the upper portion to shelter pasture, crops and soil.

(2) Triangular in vertical cross-section to cast the least possible amount of shade and to reduce the turbulence of the wind on the lee side.

(3) As tall as possible and as long as possible to give the largest possible sheltered area.

(4) At right angles to the direction of the prevailing wind also to give the largest possible sheltered area.

(5) Provided with a wing at each end to allow for veering of the wind and for wind swirling around the ends of the shelterbelt.

(6) Long-lived to give low replacement charge.

(7) In order to have most of a farm adequately sheltered from strong prevailing wind, the distance between parallel shelterbelts should be about twenty times the height of the shelterbelts. At this distance apart the zones of reduced wind velocity on the leeward and the windward sides of the shelterbelts overlap.

The type of shelterbelt which approaches most closely to the ideal form of shelterbelt consists of at least one row of a tall-growing tree such as Lombardy poplar or a eucalypt with a row of a short-growing tree or shrub of a dense type, e.g. eleagnus or boxthorn. The latter type of plant must be either shade-enduring, as the examples quoted are, or be planted sufficiently far away from the former type to avoid being shaded unduly.

It is essential that there be no overcrowding of one species by another in a shelterbelt. It is of the utmost importance too that shelterbelts be adequately protected from livestock so that dense growth will be retained close to the ground. The protecting fences should be placed well away from the stand, and, as the tree or shrub growth approaches close to the fences, these fences should be shifted further out from the stand. If trimming of a shelterbelt is necessary this should be done regularly and lightly throughout its life. Heavy trimming, especially with species such as pines and macrocarpa, must be avoided because density near the ground becomes poor or death of the trees results. If heavy trimming appears to be necessary to prevent overcrowding, then the shorter-lived species should be removed completely rather than trimmed.

Other special precautions must be taken with shelterbelts in the following situations:—

(a) Transmission lines for electric power and telephone: In order to avoid accidents and interruptions due to wind-blown branches and strips of bark falling on transmission lines, shelterbelts should be placed well away from such lines.

(b) Public roads: Shelterbelts, except of a low-growing type, should not be planted within four or five chains of a public road. Otherwise the road is likely to become unduly shaded and to receive litter blown from the trees.

(c) Drains: A shelterbelt which will grow tall should not be placed within three yards of any large drain, otherwise the trees are liable to be blown over. Another belt on the other side of the drain would overcome this danger but would impede the cleaning of the drain. With small drains which do not tend to fill with water-borne material, two rows of trees, one on each side of the drain and at least 2 yards from it, will protect each other from strong wind and will so shade the drain that weed growth in it is prevented. If the belt is protected from livestock and kept dense close to the ground, especially if a border row of shrubs is provided, then there will be good shelter. Tile drains and mole drains should not be placed within root-range of trees and shrubs and vice versa.

(d) The homestead: to avoid shading of the house and garden, shelterbelts should be grown 3 or 4 chains away from the homestead. Low shelter provided by dense hedges near the house will give adequate extra protection. The paddocks between the shelterbelts and the garden hedges will be well sheltered and will be valuable as holding paddocks for stock.

Exercise 1.—Observe carefully the shelterbelts in your district recording such features as height, number of rows in the belt, number of different species in the belt, distances apart of species, distances from protective fences, density near the ground, distance of one belt from another, suitability of species to the locality. Evaluate each shelterbelt according to its apparent effectiveness. Where a shelterbelt is obviously ineffective, give reasons why it is so and suggest measures which could be taken to make it effective.

FARM WOODLOTS

Stands of closely planted trees in blocks are called woodlots. There are four main types of farm woodlot according to function:—the timber woodlot, the firewood woodlot, the soil-conserving woodlot, and the weed-smothering woodlot. All four types may be combined in one, but best results are obtained by keeping them separate.

To get high quality timber for posts and buildings it is necessary to have a special woodlot, the *timber woodlot* in which the best forestry practice, i.e. *silviculture,* is carried out. Broadly this means that trees suited to the area (which must be accessible) and capable of producing good timber are planted at distances apart proper to the species. At the appropriate stage of growth the trees have their side branches sawn off close to their trunks, to allow growth of timber free from knots, and some trees are removed to increase the growth of the remaining trees and the total yield of useful timber. The thinnings are valuable for posts, poles and firewood, and perhaps also for second-grade sawn timber and battens.

Exercise 2.—Measure the height of a tree and estimate the volume of timber in the tree in a way such as that given in *N.Z. Forest Information Series No. 19,* Section IV.

For firewood it is desirable to have accessible to the homestead a *firewood woodlot* with an area of one or two acres. This could include at first a small portion of the area devoted to a species like radiata pine or one of the wattles for quick production, and the rest of the area made up of slower-growing species like eucalyptus for better quality firewood. Trees for firewood should produce wood with high heating value, be easy to split, and should be able to regenerate well from the stumps. The practice in which trees are felled and the stumps trimmed to shed water and to produce successive crops of regrown timber is called *coppicing.* Usually only one shoot of the regrowth from the stump is allowed to develop. As well as eucalyptus, trees suitable for a firewood woodlot are oak, plane, ash and sycamore. Trees should be felled in the winter in sufficient quantity to supply enough firewood for the following winter. A cord of firewood is a stack 8 ft. by 4 ft. by 4 ft.

Farmland which is steep and which has become unstable following the rotting of the roots of the original tree covering may provide a situation for a *soil conserving woodlot.* If the fencing of such farm land to prevent access of stock to it is not likely to lead to regeneration of scrub and native bush sufficiently quickly to stabilise the land, then a woodlot planting of quick-growing exotics would provide the necessary soil anchoring. (See Chapter 16.)

Trees suited to the locality would be chosen for such work. Commonly used trees are: Pinus radiata, Cupressus macrocarpa, Eucalyptus species, and, in very unstable ground, various varieties of poplars, willows, and root suckering plants. (See the next section.)

Where weeds like gorse and blackberry infest uneven and unploughable ground, the two-fold purpose of suppressing the weeds and providing timber can be achieved by planting there a *weed-smothering woodlot.* Fast-growing trees are necessary and radiata pine is one species which is pre-eminently suited to the two-fold purpose.

TREES FOR WOODLOTS

The tree which produces by 30 years of age a far greater volume of timber than any other species grown in New Zealand is the radiata pine (*Pinus radiata*). Given a good strain of tree and proper silviculture, radiata pine will provide a soft timber very suitable for general building purposes. Thinnings can be used for posts if treated with a preservative such as creosote. Slower growing but producing a more durable and tougher timber is the macrocarpa (*Cupressus macrocarpa*), a tree of many parts on New Zealand farms. Besides being a good shelter tree against both wind and sun, it produces, under proper woodlot management, tough timber of low density, free from knots, durable in the ground and suited to many uses on a farm.

Next in importance of the farm timber trees in New Zealand come the eucalyptus species. In general, species of this genus produce timber which is hard, dense and strong and therefore eminently suited to conditions of hard wear and heavy strain as in bridge stringers and deckings, gates and yard railings. Several species are also durable in ground and so suitable for fencing posts, especially strainers. While most eucalyptus trees will not withstand heavy frosts, there are some useful ones which will, notably the Tasmanian bluegum (*Eucalyptus globulus*), the ash eucalyptus (*E. gigantea* and *E. regnans*), and the most cold-resistant of all, the cider gum (*E. gunnii*) which grows well in high country in the South Island. Where frosts are not too severe (10° to 12° F.) the best eucalypts for milling and for fencing are white stringybark (*E. eugenioides*) and the yellow stringybark (*E. muelleriana*). Other valuable species where frosts are not above 12° F. are blackbutt (*E. pilularis*), *E. botryoides, E. saligna, E. rostrata, E. microcorys* and *E. sideroxylon.*

WIDELY SPACED PLANTING OF TREES ON A FARM

Shade for livestock, feed for livestock and soil conservation are all functions commonly performed by widely spaced trees, singly or in small groups, on pasture land.

Livestock, especially sheep and pigs, benefit from shade during hot, sunny weather. Such shade is efficiently provided by single trees within a paddock. Because deciduous trees let the light through during the winter and usually withstand trimming well, they are preferred to evergreens for this purpose. The pasture remains dense under trimmed deciduous trees, and build-up of disease there due to stock camping is at a minimum. Some of the more common trees suitable for shade in farm paddocks are:—weeping willow, planes, poplars, sycamore, Japanese walnut, oaks, and hardy fruit-trees.

Where the summer is often dry, spaced trees, especially poplars and planes, can help to solve the summer fodder problem. To provide fodder for sheep and cattle when pasture growth is scanty in the summer, the branches of the trees are sawn off to within 2 to 4 feet of their trunks. Removal of branches in this way is called *pollarding*. It may mean a greater extent of removal than this. Trees lining streets are often heavily pollarded, the branches being removed right back to the trunks. 'The pollarding of three or four trees daily will provide a complete ration of leaf for 500 ewes.' In order to let in sufficient light for pasture growth beneath the trees, they should be pollarded every two or three years.

To prevent soil erosion on hilly farming land, other than the very steep land, planting of deciduous trees and light canopied evergreens is valuable, especially for stabilising land tending to slip, and as a check to gullying. (See Chapter 16.) On the gentler slopes subject to soil movement, widely spaced planting of trees, *spot planting* as it is called, will furnish tree roots which will anchor the soil without adversely affecting the pasture. If pollarded deciduous trees or eucalyptus trees are used, pasture will be maintained beneath them. The steeper slopes subject to soil movement will require close planting and perhaps, as mentioned earlier, complete afforestation. Spot planting, while primarily concerned with stabilising the soil of hill country pastures to give a balance between the demands of land stabilisation and the demands of stock grazing can, nevertheless, be designed to provide also shade and fodder for livestock and timber for posts and battens as the trees reach maturity.

Species for Preventing Soil Erosion

To prevent wind blowing soil from cultivated paddocks and for holding back wind-blown sand, dense shelterbelts at right angles to the prevailing wind are required. Trees suited to the locality will be used but there are few species which tolerate salt-laden winds. The most tolerant are *Cupressus macrocarpa,* the maritime pine (*Pinus pinaster*), *Pinus radiata,* the Corsican pine (*P. laricio*), the prickly coned pine (*P. muricata*), and the spiny acacia (*Robinia pseudacacia*).

On hill country where gullying is developing, silver poplar (*Populus alba*) is of outstanding value because it establishes easily from cuttings or from posts, multiplies by suckers in moving soil and is usually not chewed by livestock. Willows too are valuable largely because of the dense mat of roots they produce. Suitable species are:—the pussy willow (*Salix caprea*), the crack willow (*S. fragilis*), the golden willow (*S. vitellina*) and the bitter willow (*S. purpurea*). Cuttings may be used, but where stock graze it is necessary to plant posts 3 inches or more in diameter which should be rammed in tightly. Except with bitter willow some kind of protection against stock chewing is usually necessary.

Tree lucerne or tagasaste (*Cytisus proliferus*) is also useful on this type of country but only in places well protected from livestock. It establishes easily from seed *in situ* or by transplanting provided the roots are disturbed as little as possible. A durable timber tree which is also a suckering tree suitable for controlling gullying is the shipmast locust (*Robinia pseudacacia,* variety *rectissima*). Even from trees only 15 years old the timber is very durable and suitable for fence posts. As the shipmast locust sets little seed, it is propagated by pieces of root about 2 inches long.

Deciduous trees are usually the best for spot planting, notably the fast-growing poplars, namely Lombardy poplar (*Populus nigra,* variety *stricta*), Japanese poplar (*P. yunnanensis*), black Italian poplar (*P. serotina*) and *Populus robusta.* The species of willow given for controlling gullying are also suitable for spot planting.

Where both shade and summer food for livestock are important considerations the following species have proved valuable:—the Oriental plane (*Plantanus orientalis*), the poplars, as given above, and where wind is not too severe, the weeping willow (*Salix babylonica*). Other shade and timber species are:—sycamore (*Acer pseudo-platanus*), horse chestnut (*Aesculus hippocastanum*), Spanish chestnut (*Castanae sativa*), the oaks (*Quercus robur* and *Q. pedunculata*), and the ash (*Fraxinus excelsior*). Shade and fruiting species are:—common walnut (*Juglans regia*) and Japanese walnut (*J. manchurica*). Outstanding for tolerating waterlogged soils are the alders, the common alder (*Alnus glutinosa*) and the Italian alder (*A. cordifolia*).

Of the evergreen trees suitable for spot planting there are:—the eucalypts of various species, varying in suitability according

NOTE:—Before planting silver poplar, pussy willow and crack willow, the local authority should be consulted to find out if any of these species has been declared a noxious weed in the locality.

to conditions of temperature and soil-water content; the wattles especially the black wattle (*Acacia ducurrens,* variety *mollis*), silver wattle (*A. decurrens,* var. *dealbata*) and the brush wattle (*Abizzia lopantha*). Finally may be mentioned the evergreen oak (*Quercus ilex*) of wide habitat range, capable of withstanding heavy trimming, and easily established from its acorns.

THE LIFE OF A PINE TREE

A pine tree is one of the conifers or cone-bearing trees which belong to the large group of plants called *gymnosperms,* or naked seed producers. Chief among the gymnosperms are pines, firs, spruces, podocarps, cedars, larch and yew. Although some New Zealand native trees are called pines, there are no true pines native to New Zealand. The kauri belongs to the monkey puzzle family; rimu, totara, silver pine and several other so-called native pines are really podocarps, and there are two native cedars. All coniferous trees, except the larch, metasequoia and taxodium, are evergreens, and all of them except the cypresses, some of the podocarps and the yew, have needle-shaped leaves. Unlike flowering plants, gymnosperms have ovules which are not enclosed in an ovary so that the pollen can reach the ovules directly without having to germinate on a stigma. After fertilisation the seed develops on scales which become woody and gape when the seed is ripe, letting the seed escape.

The pine tree is a typical gymnosperm. In the early spring staminate or male cones are produced in clusters near the ends of the branches. Each cone, about half an inch or so in length, contains spore cases holding spores which turn into pollen grains each with a pair of wings. Usually in the month of August the male cones shed their pollen which is carried on the wind and may make prominent deposits in such places as gutters and puddles. After shedding their pollen the male cones fall off the tree. The carpellate or female cones are much larger than the male cones and remain on the tree for several years. (See the diagram of the life cycle of a pine tree.)

Pollen grains sift between the scales of a ripe carpellate cone and lodge in the micropyle to effect pollination after which the scales close. A peculiar feature of pines is the long lapse of time between pollination and fertilisation, about a year. After the closing of the micropyle, the pollen grain produces a pollen tube which grows towards the egg in the ovule. About a year after pollination the pollen tube reaches the egg, bursts, and one of two male nuclei from the pollen tube unites with the egg nucleus to form a zygote nucleus. By division of the zygote an embryo is formed which, along with the rest of the developed ovule, makes a seed.

After pollination and until the seeds ripen the scales of the pine cone remain firmly closed. Then the scales become separated and the seeds, each with a wing attached, are dispersed on the wind. On reaching a suitable place the seed germinates, the embryo growing into a seedling with several cotyledons and eventually into a pine tree.

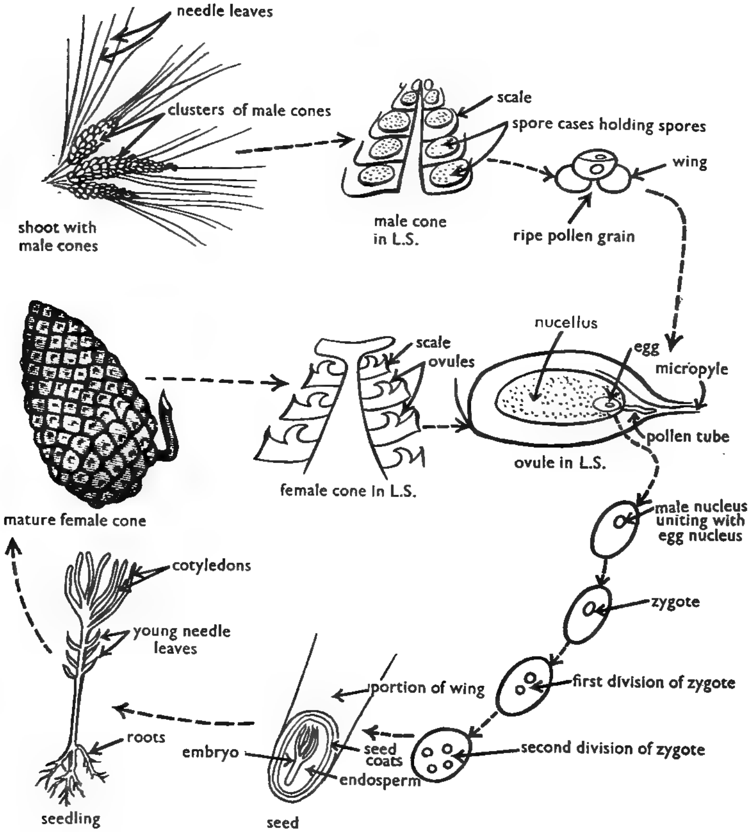


FIG. 104. Life cycle of a pine tree

Exercise 3.—(a) Observe a lone pine tree or one in a row and note its shape in outline. Contrast the shape of an old pine tree with that of a pine tree which has not reached old age. Record the number of needle leaves on a dwarf shoot. Look for scale leaves and note where they are present. Observe and sketch a pine needle in cross-section. Observe the bark, how it is fissured and state why it is fissured. Look at prepared slides of pine wood in L.S. and T.S. under a microscope and draw and note the shape of a wood cell called a tracheid.

(b) In the early spring look for young male cones. Take one, cut it lengthwise, examine the cut surface under a lens and sketch what you see. When these cones are ripe, collect some of the pollen and observe it under a microscope.

(c) At or about the same time study a pine branch and note female cones of three seasons as follows:—near the tip on the new season's growth, young cones about to be pollinated; at the end of last year's growth, cones which were pollinated last spring; and on two-year-old wood, cones pollinated the spring before last and containing ripe seeds. Taking a one-year-old cone, cut it lengthwise and observe and sketch the internal structure. Are the ovules on the upper or the lower surfaces of the scales? Dissect out a scale and observe it. How many ovules are there to each scale? Sketch a scale showing the ovules.

(d) Put a ripe cone in a warm place, and, when the scales separate, shake out the seeds. Cut a seed lengthwise and observe the cut surface under a lens. Draw what you see and label the parts.

(e) Sow some pine seeds, observe the development of the seedlings, and, when the first foliage leaves appear, make a sketch of a seedling. Count the cotyledons.

FARM HEDGES

Although large trees such as radiata pine and macrocarpa if kept regularly and lightly trimmed can acts as good hedges, it is the smaller trees and shrubs which are generally used for hedges on farms. The main function of a hedge is shelter for livestock so its most important characteristic is density of foliage especially near the ground. Other desirable characteristics are:—proof against stock, ease of establishment and ability to withstand trimming. No plant is capable of making a good hedge under all farming conditions, but there are some which come close to this ideal. African boxthorn (*Lycium ferocissimum*), common barberry (*Berberis vulgaris*) seedless barberry (*Berberis vulgaris,* var. *asperma*) and eleagnus (*Eleagnus parviflora*) have few faults but are not successful in the colder parts of the South Island. There gorse (*Ulex europaeus*) is the most generally useful hedge plant.

Some shrubs make excellent hedges but have to be permanently protected from livestock. The commonest of these are bamboo

(*Pseudo-sasa japonica*), pampas grass (*Cortaderia dioica*), New Zealand flax (*Phormium tenax*), tree lucerne (*Cytisus proliferus*) and Chinese privet (*Ligustrum sinense*).

Small trees which make excellent shelter as hedges but which have to be protected from livestock and tolerate only light trimming are as follows:—Lawson's cypress (*Chaemaecyparis lawsoniana*) in well-drained but not too dry soil and without strong wind including salt-laden wind; Bentham's cypress (*Cupressus lusticania*, var. *Benthami*) able to withstand wetter soils than Lawson's cypress; and Arizona cypress (*Cupressus arizonica*) for dry situations.

Exercise 4.—Name the chief farm hedges used in your district. With each mention any defect which is apparent, and explain, if possible, the reason for the defect, e.g. boxthorn hedge failed in one stretch where the soil is very wet.

PROPAGATING TREES AND SHRUBS ON A FARM

There are cogent reasons for a farm having its own tree and shrub nursery:—losses in transplanting are low because the time between lifting and placing in permanent position is short; the plants are available when required; varieties attuned to the local conditions are used; and seedlings are acclimatised to the locality.

Propagating may be by seed, cuttings and posts. Most trees and shrubs are best raised from seed in the nursery, but in some cases, as with spot planting of oaks, sycamore, walnuts, and tree lucerne, the seed or fruit may be sown *in situ*. Seed is collected from parents of good type when the fruits are ripe, and stored in a cool, dry place. In the spring the seed is sown in good garden soil. Wrenching is carried out in the following autumn.

Propagating by cuttings applies mainly to poplars, willows, plane, privet and seedless barberry. The cuttings are taken from good types of tree in the autumn just before leaf fall, of mature current season's growth, straight and about a foot long, and cut close below a bud at the base and close above a bud at the tip. Planting may be done immediately in good garden soil in rows 18 inches apart with 6 inches between the cuttings in the rows. Each cutting is placed base downwards to three-quarters of its length in a cleft in the soil made by insertion of a spade and before removal of the spade. As the spade is removed, the cutting is kept in place with the foot and the soil treaded firmly around it. If the cuttings cannot be planted soon after collection, they should be tied in bundles and stored in damp sawdust. After planting, the cuttings are kept weeded, and are wrenched in the following autumn. Before planting in their permanent positions in the winter, the rooted cuttings should have their shoots pruned heavily.

Spot planting of poplars, willows and plane trees may be done by cuttings, but, where livestock are grazing, it is better to use long, stout poles about 10 feet long and at least 3 inches in diameter. These are placed in post-holes 3 feet deep and rammed firmly. With this method of planting there is little loss of plants by stock rubbing and chewing, for the shoots in the upper part of a live post, being out of reach of the stock, sprout unmolested, and the post being firm develops roots readily—and without injury. Under some conditions it may be advisable to have additional means of protection of the posts from livestock such as planting in threes in tripod formation with tying at the top, and coating the lower surface with tar.

Exercise 5.—(a) Sow seeds of Cupressus benthami or C. arizonica in the spring. In the autumn observe the range of types in the seedlings. Select the best seedlings for future use, those which show high density of foliage and drooping branches, eliminating the open, upright types. (b) Make and set cuttings of various deciduous trees and shrubs in the late autumn. Observe their progress, wrench and prune at the proper time, and transplant the rooted cuttings into permanent positions.

READING

'Farm Trees and Hedges', Yeates, J. S.
Massey Agric. College Bulletin, No. 12

N.Z. Forest Service Information Series,
Nos. 18 and 19, (Woodlots)

N.Z. Journal of Agriculture,
'Eucalypts', April 1958; 'Trees on the Farm', Mar. 1955 onwards; 'Shelter', Dec. 1952, Aug. 1952, May 1946; 'Cypresses', July 1951; 'Pines', Dec. 1950

Canterbury Chamber of Commerce Agric. Bulletins,
Nos. 342, 310, 270

Massey Agricultural College Sheepfarming Annual,
1957, page 49

N.Z. Forest Service Publicity Item, Nos. 6, 7, 18

Rural Education Bulletin,
'Biology and Folk Lore of Trees', and 'Conifers', 1957 and 1958

Forest Trees and Timbers of New Zealand,
N.Z. Forest Service

Trees of New Zealand, Cockayne and Turner

22

Reproduction

In both plants and animals, reproduction, or the giving rise to new, independent offspring, is either sexual or asexual. While in animals reproduction is usually sexual, in plants, especially in the lower plants such as bacteria and fungi, it is frequently asexual as with binary fission (see Chapter 12) and spore formation (see Chapter 24). Sexual reproduction in higher plants has already been discussed for flowering plants (angiosperms) in Chapter 7, and for gymnosperms in Chapter 21. In this chapter we shall be concerned mainly with asexual reproduction in flowering plants, referring to sexual reproduction in these plants only in connexion with raising seedlings.

Flowering plants reproduce by:—

(a) Vegetative reproduction which consists essentially in the separation from the parent plant of vegetative portions which develop into new individuals. Twigs, buds, leaves, and roots variously take part in the process of vegetative reproduction.

(b) The production of seeds, as a result of sexual reproduction.

VEGETATIVE REPRODUCTION

The terms 'natural' and 'artificial' are used in distinguishing the modes of vegetative reproduction.

The term 'natural' is applied to the processes which take place without the interference of man. Instances are provided in the growth of:—(a) potatoes from tubers; (b) strawberries from runners; (c) willows and poplars from suckers; (d) narcissi from bulbs; (e) gladioli from corms; (f) couch grass and iris from rhizomes.

The term 'artificial' is applied when plants reproduce vegetatively because of the efforts of man. This is also referred to as *plant propagation.*

The commonest methods of propagation are (a) cuttings, (b) layers, (c) division, (d) grafting, (e) budding.

CUTTINGS

The term 'cuttings' is applied to the propagation of a plant by the use of a detached portion of root, stem, or leaf. Propagation by cuttings often saves time. Further, there is the assurance that the new plant is similar in essential characters to the parent plant.

In making cuttings of leafy herbaceous plants, e.g., lobelia, geranium, firm short-jointed growths should be used, and gross sappy wood avoided. The cuttings should be set in boxes of warm, loose soil or compost, which may be prepared as indicated in Chapter 12. It is desirable to provide protection by the use of a frame or of a sheet of glass. This will ensure a warm, close atmosphere which prevents excessive transpiration and encourages root formation. Two-thirds or slightly more of the cutting should be inserted in the soil, which should be firmly pressed round the cutting, care being necessary, however, not to injure the bark. All leaves except two or three upper leaves should be removed so as to reduce the moisture lost by transpiration while the root system is being developed.

For most hardy shrubs, e.g., rose, lauristinus, barberry, the cuttings should be about 9 inches long and taken from wood of the previous season's growth. Generally, they should be made in autumn, for then the stems contain a sufficient store of food for the production of callus and root. In some cases, e.g., red currant, gooseberry, rose stock the buds on the underground part must be removed; otherwise they will sooner or later produce an inconvenient number of suckers. Gooseberry and red currant cuttings require to be 15 inches long to make good plants.

In preparing nearly all cuttings it is desirable to cut immediately below a joint or node where the wood is more compact and hence more likely to withstand decay. In many cases it is necessary to take shoots of current season's growth with a 'heel' of old wood which minimises the likelihood of decay.

The use of a sharp knife is desirable to avoid injured or bruised tissue which is prone to decay.

Cuttings require to be set in porous soil free from decaying matter which might infect the wood and cause it to rot. A porous medium favours the development of a strong root system. It need not contain much nourishment, for the cuttings should be planted out as soon as they are established.

LAYERING

Layering is a means of propagation resorted to with plants which cannot be reproduced readily from cuttings. Layering usually consists of bringing shoots in contact with the soil by bending and fastening them down if necessary, and of inducing the formation of roots from the portion touching the soil.

The strongest plants are obtained by taking only one plant from each shoot, and for this purpose the soil is applied to a bud at a convenient position on the shoot. If buds are close together select the strongest and remove the others. *Serpentine layering* enables several plants to be obtained from the one shoot.

Usually it is advisable to make an upward slanting cut in the portion of the branch which is to be covered with soil. The cut should extent about half-way through the shoot on the under side, and the cut surfaces must be kept apart by inserting a small piece of stone or other object which will prevent healing.

All buds or leaves not needed to form branches must be removed from the shoot which is then firmly pegged in position and covered with soil to a depth not exceeding five inches.

Twisting and notching of the stem and ringing, i.e. the removal of a circular band of bark, are sometimes practised instead of cutting, the object in all cases being to check the downward flow of sap and stimulate the development of roots from the soft callus which forms where the sap has been checked. In the process of layering the shoot is not detached from the parent plant to form a new individual until it has developed sufficient roots. Hence layering is more reliable than propagation by cuttings, for the shoot receives a supply of moisture and food from the parent plant until it has become firmly established.

Shoots are generally layered in summer or autumn. In some cases they must be untouched for two years, e.g., rhododendron, camellia. Soft-wooded plants root at once, e.g., clematis.

Wisteria, magnolia, salvia, carnation, guelder rose, honeysuckle, and various varieties of roses, are other plants which may be propagated successfully by layering.

MOUND LAYERING OR STOOLING

This essentially consists in encouraging suckers or growth from basal buds. Shoots so produced are notched close to the surface and the base of the plant covered with soil, with the result that roots develop from the portions of the shoots embedded in the soil. In the spring or following autumn the rooted shoots are planted out into rows. Mound layering is practised in the propagation of quince or apple stocks (Northern Spy).

Aerial Layering

Also known as Chinese layering and marcotting, aerial layering is designed to induce a branch of a tree or a shrub situated high above the ground to produce roots so that the rooted branch when cut off the plant may be grown as an independent plant. At any time of the year, but preferably September to March, a suitably placed shoot, about half an inch or so in diameter of a selected tree or shrub has a tube of sheet plastic (a plastic bag with the bottom slit open is suitable) put down over the shoot and its lower end sealed to the shoot with plastic tape. The lower part of the shoot, just above the sealed end of the plastic tube, is then wounded either by cutting from half an inch below a bud up about one and a half inches to make a tongue, which should be kept open by inserting a sliver of wood, or by ring-barking a band one and a half inches wide taking care not to cut into the wood. Root stimulating hormone powder is then dusted over the cut surface, in the slit in the case of the former method and on the upper edge of the cut bark of the latter. Pulling the plastic bag up the shoot, damp moss or damp compost soil for a rooting medium is packed into the bag around the wound and the upper edge of the bag is sealed watertight to the shoot. The aerial layer is left for about a year until root development is prominent; the new plant is then sawn off the parent below the bag which is removed carefully so that the roots are not damaged. Potting of the plant is the next step together with pruning to reduce transpiration and to gain a balance between root and shoot. When the plant is growing well, it is set out in its permanent position.

Aerial layering may be applied to fruit trees, e.g. peach, and to many ornamental shrubs such as rhododendron and magnolia.

Division

Many herbaceous perennials and all bulbous plants are commonly propagated by division. With raspberries, for instance, the new shoots produced at the base of the plant should be separated from the parent plant after flowering. The offsets of narcissi bulbs should be taken away and planted apart from the parent bulb. Clumps of perennial flowering plants like delphinium are lifted in the autumn or just before growth starts in the spring. Each clump is cut or divided into pieces so that each piece, as a transplant, has a shoot and a root.

Grafting and Budding

These are among the most important methods of propagating plants. They are practised for one or more of the following reasons:—

1. To multiply varieties that do not come true from seed:—With our main fruit trees, and with many ornamental plants there is no certainty that an individual grown from seed will exhibit the characters of the plant from which the seed was obtained. Indeed, the majority of fruit tree seedlings may be expected to be inferior in quality to the parent. Hence, to maintain the quality of a species and to perpetuate the special characters for which it is grown, it is necessary to practise grafting, which results in the qualities possessed by the limb from which the scion or bud was obtained being exhibited by the new plant which develops.

2. To save time:—Many plants, particularly pears, apples, and oranges, when grown from seed, do not assume the fruiting habit for ten or more years, whereas when propagated by grafting, fruit may usually be obtained with ease the second or third year, according to the treatment practised.

3. To control disease:—An outstanding instance of this is the use of Northern Spy stocks for apples so as to obviate infection of the root system with woolly aphis. Northern Spy apples are resistant to woolly aphis. Hence, if an apple tree is on a Northern Spy root system there is reasonable assurance that the woolly aphis will not be found upon its roots.

4. To multiply plants which cannot be raised economically by cuttings.

5. Several other objects of budding and grafting are discussed in the following pages in describing the kinds of stocks.

Grafting

Grafting is the operation of bringing together the cut surfaces of two plants of the same family so that a union results from the growing together of the two cambium rings.

The length of the stem taken from a plant which it is desired to propagate is called the 'scion'. The plant to which the scion is attached in order to be provided with a root system is called the 'stock'. It is of great importance that suitable stocks be obtained: the use of unsuitable stocks frequently leads to lack of vigour and to disease.

For apples, Northern Spy stocks have generally been used in the past but are now largely replaced by East Malling stocks numbers 12 and 16. Number 12 is the more vigorous and is suited for poor soils and those with a clay subsoil. They are both fairly resistant to woolly aphis. Dwarf apple stocks are also available, mainly for home gardens since the trees grow to a height of only a few feet.

For apricots, the stocks provided by seedlings raised from apricot 'stones' are in general the most suitable. Stocks raised from peach 'stones' are the best for the apricots on sandy soils. For heavy or poorly-drained soils the Myrabolan plum stock is best, but, if possible, apricots should not be grown on such soils to which they are unsuited.

For peaches, peach seedlings of the variety Golden Queen are in general use but the Myrabolan plum stock should be used for moist soils. In raising peach and apricot seedlings it is advisable to use well-developed stones obtained from the fruit borne on vigorous, healthy trees.

For plums, the stocks generally used are the Myrabolan and Marianna plums, the former being the better for heavy, damp soils; the latter for lighter soils.

For pears, the best stocks are generally pear seedlings, which should be raised by using the 'pips' of hardy varieties preferably the Keiffer pear. The quince, preferably quince A, is sometimes used for the pear. It has a dwarfing effect and brings the pear into bearing earlier. Dwarfing is important in private gardens when two trees have to be grown for purposes of pollination. It produces a fibrous mass of roots near the surface and therefore suits heavy soils with clay subsoils better than pear stocks the roots of which tend to penetrate into the subsoil.

The scions used should be taken from one-year-old wood and obtained only from healthy trees, and it is further desirable that these trees should have demonstrated good bearing qualities while at the same time they should not be declining in vigour. Sound, matured wood with well-developed wood buds being desirable, the tips and lower portions of shoots must not be used. The buds on the scions should be a little more backward in growth than those on the stocks. To ensure this it is usually necessary to cut in the winter the wood to be used for scions and to place it in a cool, shady place or cover it with a shallow layer of moist soil to prevent the wood from drying out. Two to four buds are sufficient on a scion. Of the various methods of grafting the following are the most common:—

1. *Whip and tongue grafting* is suitable when stock and scion are about the same size and relatively small—up to about 1 inch in diameter. A smooth sloping cut about two inches long is made diagonally across both stock and scion. If a single swift cut is made the necessary smooth surface is easily obtained, whereas a ridged surface usually results when several cuts are employed to obtain the surface. It is well that scion and stock be somewhat similar in diameter so that as large as possible a proportion of their cambium tissues may come into contact with each other. A cleft is made in both stock and scion by splitting them a little over an inch with the knife used. They are then fitted together as shown in Fig. 105. The joint must then be covered to exclude the air completely, and also be held firmly by secure binding. For this purpose waxed cloth may be used,

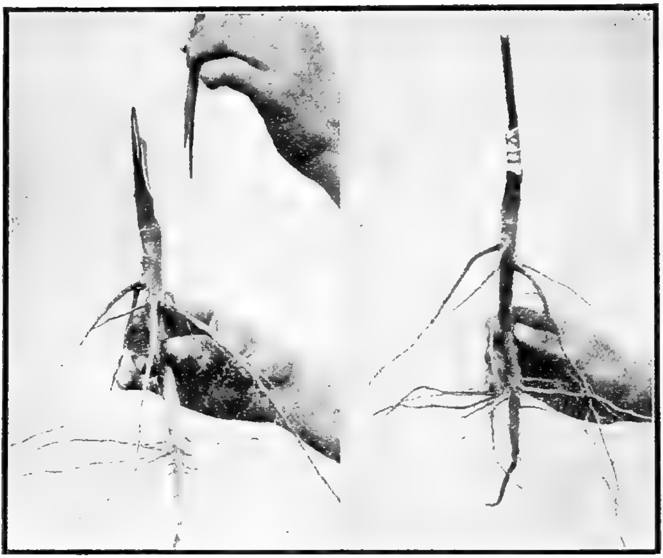


FIG. 105. The whip or tongue graft

(*N.S.W. Dept. of Agriculture*)

or the join may be firmly bound with raffia or tape and then painted with grafting wax or more simply with petrolatum. It is essential that the cambium of the scion be in contact with that of the stock. If stock and scion are uneven in size they should be placed together in such a way that the cambium layers are in contact on one side. When scions commence to grow it is advisable to examine grafts to see that the material used in tying is not injuring the stock and the scion by cutting into the wood. It is sometimes necessary to loosen the material. The 'ties' will need to be cut in about four weeks after scions begin to grow. If more than one shoot grows from the scion it is usually advisable to use only the strongest and remove the remaining ones.

2. *Crown or rind bark grafting* is adopted for renovating large trees in which the wood is too thick for convenient whip grafting. The stem of the stock is cut square, and the bark is cut downward from 2 to 3 inches as shown in Fig. 106.

The scions are cut in a similar way to those used in whip grafting except that no cleft is made and that a shoulder is made to rest on the stock (Fig. 106). The scion is pushed down between the wood and the bark which is loosened at the top of the cut to allow the pointed end of the scion to be pushed down into position. Generally, two or three scions should be inserted. They require to be wrapped tightly with strips of waxed cloth or raffia. Then to exclude air, grafting wax or green crude petrolatum should be applied around the scions and over the whole top. A substitute for grafting wax is a mixture of cow dung and clay.

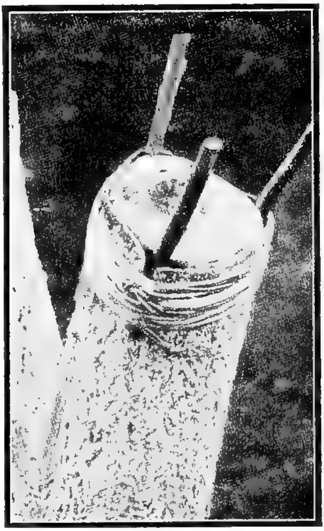


FIG. 106. Crown, rind or bark graft

(*N.S.W. Dept. of Agriculture*)

3. *Root grafting* is of importance in connexion with the raising of Northern Spy apple stocks and other plants which do not grow readily from cuttings. A piece of yearling Northern Spy

stem about 4 inches long is grafted to a piece of Northern Spy root about 3 inches long. The 'whip' method is generally followed, but wax is not required. The root graft is planted in early spring, with a short piece of scion bearing a bud showing above the level of the soil. When the sap begins to move in the root a cambium union with the scion soon results, and fibrous roots develop, thereby providing a Northern Spy stock.

Trees that have been grafted require care during the first two years. Many shoots may develop from the stock during the first year. A suitable number of these should be retained to absorb the sap and carry on desired growth, and the remainder removed. Branches on which scions failed to grow should be cut back and re-grafted the following spring. The selected shoots from the successful scions should be pruned to form a suitable framework.

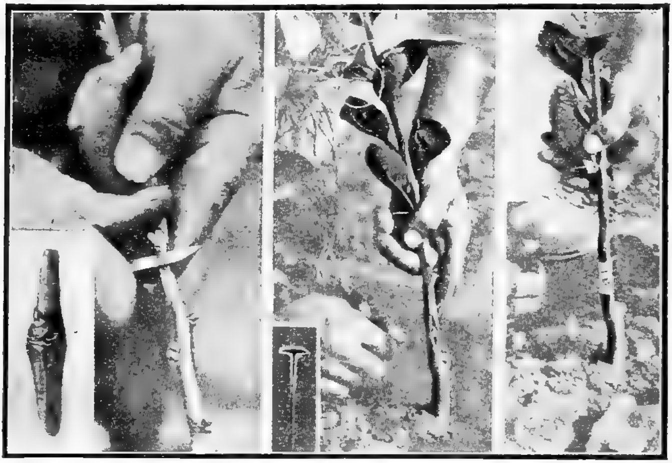


FIG. 107. Budding. *Left*: Cutting the bud; (Inset) The bud ready for insertion; *Middle*: Bud in position ready for tying up; (Inset) Stock cut to receive the bud; *Right*: The bud tied in position with waxed cloth (*N.S.W. Dept. of Agriculture*)

BUDDING

Budding is essentially the same as grafting, differing from the latter in that a single bud is applied to a stock instead of two or more buds on a scion as in grafting. Well-developed buds from healthy and heavy-fruiting trees should be used. The leaves, except portions of the stalks by which the buds may be held, should be removed from the 'bud sticks', (the twigs bearing the buds to be used) as soon as they have been severed from the tree, so as to lessen the danger of the drying of the buds and the shrinkage of the bark. Further, in hot, dry weather, to keep the bud sticks from wilting they should be wrapped in damp bagging.

Budding is done any time during the growing season when the bark may be lifted easily from the wood. It is well to avoid hot, windy, or wet weather. The bark rarely lifts freely after a long hot dry spell unless the ground has previously been given a good soaking with water. The current year's growth is the best for budding, but growth two or three years old may be used successfully.

METHOD OF BUDDING

The common method is known as T or shield budding. A vertical cut from one to one and a half inches long is made through the bark of the stock at the point where the bud is to be applied. Then a horizontal cut is made across the top of the first cut. The corners of the bark are slightly raised in the same operation (Fig. 107) by pressing the knife blade backwards. The bud is then cut, as described later, inserted at the cross-cut of the T and forced downwards under the bark. It is then firmly tied in place with moistened raffia or plastic tape. It is usual to leave the point of the bud slightly exposed.

To obtain the bud the knife blade is inserted in the budstick about half an inch below the bud to be used and passed under the bark for about one inch in a single clean cut so that it severs the bud with about one-half inch of bark above and below the bud and a thin slice of wood attached to it (Fig. 107). To facilitate the handling of the bud it is well to leave a short length of leaf-stalk when removing the leaves from the budstick as recommended above, (note the short stalk left with the bud below the thumb in Fig. 107). Soon after the union between the bud and the stock is effected, it will be necessary to remove or to slacken the binding material—the time for this operation varies from 2 weeks with summer budding to 6 weeks with autumn budding. In spring, when the buds are well established, the tops of the stocks must be removed, except a length about 6 inches above the bud—to this length the young growth from the bud may be tied if support is required. Growth from suckers and buds other than the inserted one must be removed.

The success of both grafting and budding depends largely on (a) rapid working to avoid drying of the delicate tissues exposed; (b) the use of sharp tools to give clean, even cuts; (c) careful accurate work in cutting and fitting scions and buds; (d) the use of healthy scions, buds, and stocks.

BENEFITS OF VEGETATIVE REPRODUCTION

(1) For plants which do not come true to variety, vegetative reproduction is the only means of retaining and multiplying desirable varieties. This applies particularly to fruit trees and ornamental shrubs. With cuttings, layering and division the new plants are identical with their parents, but with grafting and budding there is a slight variation due to the effect of the stock on the scion.

(2) Large plants can be produced in a short time.

(3) Those plants which do not seed, e.g. willow, shipmast locust and flowering plants with double flowers, can be propagated vegetatively.

(4) Plants with seeds difficult to germinate may perhaps easily be propagated vegetatively.

REPRODUCTION FROM SEED

RAISING OF SEEDLINGS

Raising plants from seed is the most general and the most natural method of plant propagation. It often imparts increased strength of constitution to plants which are generally raised vegetatively. Virus diseases may be transmitted in budding and grafting but are very rarely carried over in the seed. Also by cross-breeding of plants hybrid vigour is utilised. (See page 118.)

Taking some compost soil (see Chapter 14) place it in a seed-box and press it down firmly especially in the corners of the box. The seeds should be evenly sprinkled on the surface of the soil and covered by putting some of the compost soil through a fine sieve held above the box. Shallow pans or boxes are most suitable in the majority of cases, for with small seeds little depth of soil is required to secure germination. The water applied should be at about the same temperature as that of the air in which the plants are growing. After seed-sowing a sheet of glass placed over the box maintains a moist atmosphere and conserves the moisture: it must be removed, however, soon after germination, otherwise the seedlings become delicate and drawn. Plastic sheeting serves almost as well as glass. In the open it is often well to cover the seed drills with fine branches till the seedlings appear. These branches conserve the moisture and keep the birds off.

As discussed in Chapter 2, some seeds, before they can germinate, need a period of after-ripening. There are seeds too which need not only time after reaching maturity but also a low temperature for some or all of this time. The process of keeping ripe seeds for some time at low temperature is called the *stratifying of seeds*. Peach, plum and cherry seeds, for instance, need keeping for at least three months at a temperature of 33° to 40° F. in a moist but not wet condition to permit germination. Before trying to germinate the seeds of alpine plants they must be left over winter either under the alpine conditions or on the lowlands in a plastic bag in a refrigerator.

Seeds which come up thickly in beds or boxes must be thinned or 'pricked out' into boxes of specially prepared soil as soon as they can be handled conveniently. The distance between the 'pricked' seedlings varies with the size they will be allowed to attain in the boxes, but a space in each direction of about 2 inches is often suitable.

Seedlings which have been raised with artificial heat must be gradually hardened off before transplanting is attempted: to do this they are set out daily in the open for gradually increasing periods of time, starting with the warmest part of the day.

TRANSPLANTING

The best plants are stocky and possess well-developed roots and three or four healthy leaves. The soil should be moist and a damp day should be chosen if possible. The roots should be exposed as little as possible, and should never be cramped for space or turned upwards. The soil should be firmly pressed about them. Usually, and particularly in dry weather, part of the leaf growth should be removed in order to balance injury to the root system. When it is not convenient to wait for damp weather the transplanting is best done late in the afternoon, and the roots of the seedlings should be dipped in thin mud just before planting them or, in free soils, a little water may be poured into each hole before or after setting the plant.

Deciduous plants should be moved during their dormant season. Staking and tying to prevent the wind moving them is generally advisable. All broken and injured portions of roots should be removed with a sharp instrument forming a clean cut. Part of the top should be removed to correspond with the loss of root, and the soil should be well packed about the roots; the surface portion however, should be left loose. The plants should be placed at the same depth in the soil as they previously were growing.

BENEFITS OF PROPAGATING BY SEEDS

(1) Seedlings can usually be produced at low cost.

(2) Vigour is often prominent in seedlings due either to absence of disease or to the phenomenon of hybrid vigour.

SUGGESTIONS FOR PLANT PROPAGATION

Exercise 1.—(a) Try to raise several kinds of plum trees from cuttings, starting in late May.

(b) Layer border carnations and set cuttings of perpetual carnations in February.

(c) Reproduce a peach tree by aerial layering.

(d) Make a whip and tongue graft on an apple tree in September.

(e) Bud a peach seedling some time during the period mid-February to the end of March.

(f) Stratify peach stones or seeds of an alpine plant and sow in the spring. Compare with unstratified seeds.

READING

Canterbury Chamber of Commerce Agric. Bulletin, No. 213

Rural Education Bulletin, Mar. 1951

N.Z. Journal of Agriculture, June 1957, p. 604; Oct. 1954, p. 399; Aug. 1953, p. 123

FILMS

(The National Film Library)

'Vegetative Plant Propagation'

23

Diseases of Plants

ONE of the principal problems which the farmer and gardener have to contend with, is that of plant diseases. So heavy are the losses caused in this Dominion by plant diseases that they run into millions of pounds annually.

The condition in which the proper growth and development and other functions of an organism are interfered with is called *disease*. Such interference produces in an organism deviations from its normal structure and function which are called *symptoms* of the disease. It is often difficult, however, to draw a line between health and disease, because there may be few or no symptoms. For example, the only clearly evident symptom of virus disease in a potato crop may be low yield, other reasons for the low yield having been found wanting.

Some of the chief causes of plant disease are:—parasitic fungi and bacteria which are micro-organisms (microbes for short); viruses which may or may not be living organisms; and small animals, chiefly insects, which are generally not microscopic but macroscopic. Earlier in this book we have considered seed plants which have been parasites on useful seed plants, e.g. dodder on clover. In this chapter we shall deal with the less highly organised but not uncomplicated and much more widespread causes of plant disease. Earlier in this book reference has been made to the useful nature of many fungi, bacteria and other lowly plants. These are the saprophytes which feed on dead organic matter and without which there would be no agriculture. Reference has also been made to plant troubles caused by *excessive* amounts of soil water, soil nutrients, soil acidity, and excess wind, and to troubles caused by *insufficient* amounts of soil water and soil nutrients. Of these excesses and deficiencies only the last mentioned, deficiencies of soil nutrients, producing what are called deficiency diseases, will be considered further in this chapter.

Parasitic fungi can be seen in detail only with the aid of a magnifying glass or a microscope. They appear mainly as pipe-like threads or *hyphae* forming a mass which is called *mycelium*. Any one kind of parasitic fungus attacks as a rule only one variety, species or genus of plant but sometimes a fungus has a range extending over a larger group of less closely related plants and even unrelated plants.

Parasitic bacteria, because they usually favour a slightly alkaline growth medium such as the blood of animals, are less common causes of plant disease than parasitic fungi which prefer a slightly acid medium such as plant sap.

Virus diseases of plants, as discussed in the culture of the potato, penetrate all parts of a plant causing mottled colouring and distortion of parts. Viruses are some kind of infective agents which are so minute that they can be seen only under a specially powerful microscope, the electron microscope, which magnifies 80,000 times compared with the ordinary microscope which magnifies less than 1,000 times.

Deficiency diseases are due not to microbes or other infective agents but to lack of sufficient soil nutrients, often trace elements. (See Chapter 13.) The cure for such diseases is achieved by applying with care the elements known to be deficient.

FUNGUS DISEASES

What Fungi Are

Fungi are lowly plants which as a group are separated from most other plants by the absence of green colouring matter, or chlorophyll. As this substance is absent, they are unable to elaborate their own foods, but must of necessity live upon living or dead tissues, since it is from such sources of already prepared foods that they are able to derive their nourishment.

A typical fungus is the common mushroom, *Psalliota campestris*. The portion above ground, known as stalk and cap, is given over to reproduction; for from the lower surface, on the gills, are produced quantities of dust-like material made up of bodies each called a *spore* which is a resting cell able to germinate under suitable conditions to reproduce the fungus. Thus spores are reproductive bodies performing a function similar to the seeds of higher plants. These spores are produced in large numbers and, when mature, are discharged from the gills. But before they reach the surface of the ground they are caught by air currents and carried long distances. When they alight, should conditions prove favourable, they may germinate and give rise to a vegetative stage which eventually produces further fructifications. The stalk serves as an elevating organ, whose function is to carry the cap sufficiently high to enable the spores to be dispersed by the wind. Beneath the soil ramify very numerous thread-like structures termed *hyphae*. These are attached to the stalk, and penetrate between the soil particles. The hyphae collectively form the vegetative portion (known as the *mycelium*). They perform the function of nutrition for they absorb from the soil and vegetable debris the food substances necessary for the growth and development of the fungus. Hyphae are tube-like, and are usually divided at frequent intervals by cross-walls, or septa; each is exceedingly fine, being on an average less than 1/2,500 of an inch in diameter. The cap and stalk consist of masses of these hyphae so interwoven as to form a firm tissue.

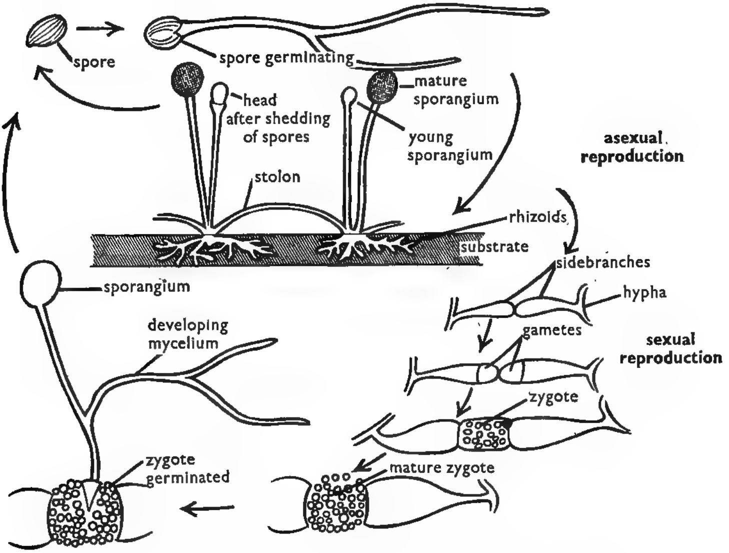


FIG. 108. Life cycle of bread mould (*Rhizopus nigricans*)

It has been shown that a mushroom obtains its food substances from decaying vegetable debris in the soil; owing to this method of nutrition these plants are termed *saprophytes*, and are said to lead a *saprophytic* existence. The majority of fungi lead a saprophytic life, and release chemical substances stored in dead vegetable and animal tissues. They thus play an important part in nature, for were they and bacteria absent, decay of such matter could not occur.

Another common example of a saprophytic fungus is the bread mould, *Rhizopus nigricans*.

If moist bread or a similar food is left enclosed for a few days, it becomes covered with a soft, white, thread-like growth or mycelium. Later the mycelium develops erect hyphae with black heads which contain spores to be dispersed by the wind. When a spore lands on a damp place, it germinates (see the diagram of the life cycle), and, if there is a food supply there also, it produces a mycelium made up of hyphae of three kinds. One kind, the *rhizoids*, hold the fungus to the body on which it is living, the *substrate*, and secrete enzymes to digest the food which is passed to the rest of the mycelium. Other hyphae, the stolons, grow just above and parallel to the surface of the substrate, and a third type grows erect from the points where the stolons join the rhizoids and develops black heads holding spores. This method of spore formation represents asexual reproduction.

Sometimes two lots of mycelia from plants of different strains, called *plus strain* and *minus strain*, come into contact. Then sexual reproduction takes place as follows:—a short, thick side branch from each hypha (see the life cycle diagram) grows towards another until they meet. The ends of each side branch become divided off and represent gametes which then unite to form a zygote. After developing a thick, black wall with a rough outer surface, the zygote, stored with food reserves, rests. When favourable conditions develop, the zygote germinates producing a mycelium which after a time produces spores asexually.

Exercise 1.—Leave some damp bread or a piece of pumpkin in an enclosed space for a week or so. Using first a magnifying glass and then a microscope examine the black mould produced. Make sketches of what you see.

The fungi which cause diseases of plants are essentially similar in structure to the mushroom and the bread mould, but differ mainly on account of their parasitic habit. By way of examples a fungus called *Pseudopeziza trifolii*, and one called *P. medicaginis* causing Leaf Spot of clover and lucerne respectively have been chosen. Only in a few instances are these diseases responsible for serious economic loss.

On the leaves of these plants may be noticed numerous brown spots, which on account of their small size, are frequently overlooked. Microscopic examination shows the leaf cells of such a spot to be brown and shrunken, an indication that they are dead; and it is these brown cells which give to the spot its characteristic appearance. The hyphae causing the spot penetrate between the cells of the leaf and absorb from them the food substances contained therein. In consequence the cells die and turn brown. These hyphae are similar to those of the mushroom, and perform similar functions—which are those of obtaining from the host plant their food substances. (The plant attacked by an organism is termed the *host.*)

After the parasitised cells have been killed the hyphae in the middle of each spot become aggregated into small masses, and finally give rise to minute cup-like structures from the interiors of which spores are produced. These structures are the fructifications which, although very different from the cap of the mushroom, yet perform the similar function of spore production.

Spore dispersion with such an organism is effected in quite a different way. The small fructification is provided (in this instance) with a minute apical pore, and when the spores are ready for dispersal this opening is seen to protrude through the surface of the dead tissues, and through it the spores are ejected, to be carried by rain splashes, insects, or even wind, to adjoining leaves.

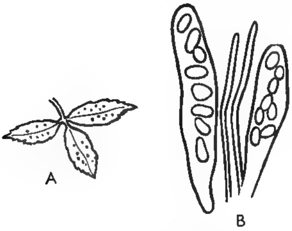


FIG. 109. Leaf spot (*Pseudopeziza medicarginis*) of lucerne (*Medicago sativa*). A: Leaf showing spots; B: Part of the fructification in the middle of a spot, showing spore bags (asci) each holding 8 spores, and special hyphae (paraphyses) which help to force out the spores when the asci are ripe and burst

(*After Samson and Western: 'Diseases of British Grasses and Legumes'*)

This fungus lives at the expense of the living cells of the leaf—therefore it is termed a *parasite,* and is said to lead a *parasitic* existence.

In both these fungi two types of tissues are present:—

(1) A vegetative tissue, consisting of numerous hyphae, which penetrate soil, decaying vegetable or animal matter, or living plant or animal tissues; and

(2) A reproductive tissue, formed for the purpose of producing structures (as spores) capable of reproducing the fungus.

We have considered two types of fructification, both belonging to types of fungi which possess but one reproductive stage. With the great majority, however, one or more different stages of fructification are interpolated in the life cycle before the final stage appears. In general there are two types of fructification produced: the first stage—termed the *conidial* stage—being concerned with the rapid production of summer spores or *conidia* during the growing season of the host plant, or in the case of saprophytes, the (usually) warmer months of the year; the second type, or resting type, serving to carry the organism over some unfavourable period—usually during the winter when leaves and fruit are not present. With parasitic fungi it is frequently the conidial stage which is the actively parasitic one, the over-wintering stage appearing on the dormant or dead tissues of the host, or on or in the ground.

With certain fungi, as with rusts, the life cycle is even more complex, for as many as five spore stages may be produced; and is further complicated in that some require more than the one host plant for the completion of their cycle, as with stem rust of wheat.

Conidia are spores each containing many nuclei. They are formed by division from the ends of hyphae. Usually borne on simple modified hyphal branches — termed *conidiophores* — they become readily detached at maturity. (See Fig. 110.) Resting fructifications, on the other hand, are more complex, and are completed only after they have undergone certain complex changes, which cannot be discussed here. These fructifications range from the simple to the complex, and in the higher forms often exhibit intricate structure. Their number and range are considerable, as may be realised by the fact that some 80,000 species of fungi have been named and described.

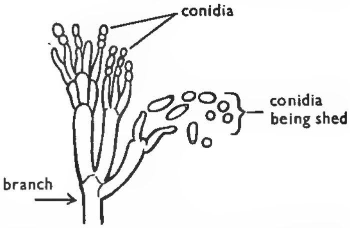


FIG. 110. Branch of *penicillium* mould bearing conidia. (*Penicillium* produces the antibiotic, penicillin)

If a spore produced from any of the different types of fructification is carried by one of several agencies to a suitable position, it may germinate and penetrate the substratum. The method of penetration differs according to the species, and to the host or part thereof attacked. If the fungus is capable of attacking a leaf, the hypha may penetrate directly through the surface of the tissues beneath, or may enter one of the stomata on the surface of the leaf. It may then penetrate between the cells, sending suckers into each and absorbing food substances in this manner, or else penetrate between the cells and absorb its food by the process of endosmosis. The hyphae of certain species penetrate directly through the cells, dissolving their way, as it were, by secretion of certain substances from their apices. In all cases, once penetration has been effected, the hypha branches repeatedly, so that in a short time the area of penetration is permeated with hyphae.

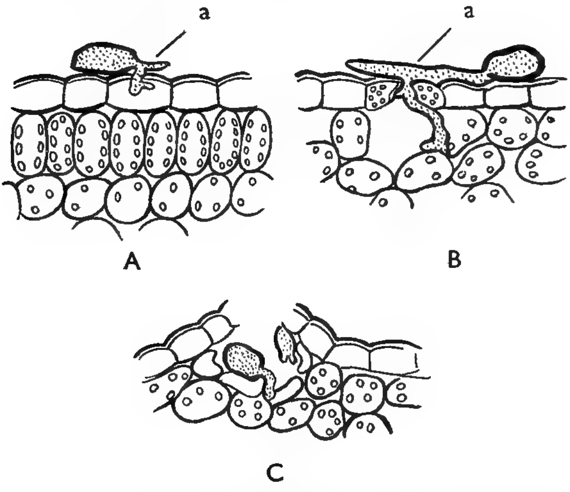


FIG. 111. Fungus threads attacking plant tissue. A: Germinating spore penetrating an epidermal cell; B: Germinating spore penetrating a stoma; C: Spores germinating in a wound; a: Appressorium or penetrating hypha

(*After Fream, rev. D. H. Robinson*: *'Elements of Agriculture'*)

In certain fungi (the powdery mildews) the mycelium remains on the surface, and the fungus obtains its food by sending through the epidermis of the host small suckers (termed *haustoria*) into the cells beneath.

SPORE DISPERSAL

Spores are carried to other hosts in the vicinity in various ways. For example, the naked conidia of mildews are readily detached and carried by wind to other plants, as are the spores of bracket fungi and mushrooms. Others are distributed by insects, being carried on their bodies. Birds, too, may carry spores attached to their feet, limbs, or beaks. Spores may be washed by rain to leaves and branches in the vicinity, or rain drops may be borne some distance by wind, carrying with them spores of numerous species. Several plant diseases are carried on the seed of the plants they attack, or upon tubers of plants, such as potatoes and artichokes.

Fungi may be carried over from one growing period to the next in several ways. Thus many fruit or bulb-rotting species live in the decaying tissues in the form of thick-walled cells of the hyphae. Or the hyphae may become agglutinated to form resting bodies termed *sclerotia*. Such structures may remain in a latent condition in the soil for several years. In many, the structures within which the spores are produced, serve to protect the enclosed spores against unfavourable conditions, and in a great many species the spores themselves are enclosed within thick impervious coats, or embedded within gelatinous coverings which serve to preserve them for considerable periods. Finally, certain fungi may pass the winter in the form of resting mycelium on or in the tissues of the host plant. The mildews are a case in point.

DISEASES PRODUCED BY FUNGI

A study of the life history of any fungus causing disease is necessary in order that methods of control may be elaborated. For if the manner in which the fungus spreads from year to year, and the range of the hosts it attacks, and like information are known, it is possible usually to plan effective methods of control. The examples enumerated below are chosen with a view to illustrating the manner in which this knowledge can be made use of in applied mycology. There are three main classes of fungi important in agriculture. They are (a) the phycomycetes or algal fungi, (b) the ascomycetes or sac fungi, and (c) the basidiomycetes or club fungi.

FUNGUS CLASS A, PHYCOMYCETES (*Algal fungi*)

This class of fungi is somewhat like algae especially in the way their gametes form and unite. (Refer back to the Bread Mould, *Rhizopus*.) Examples causing plant diseases to be described here are:—(1) *Phytophthora infestans,* and (2) *Plasmodiophora brassicae*.

(1) LATE BLIGHT OF POTATOES (*Phytophthora infestans*).—This is one of the most troublesome of the diseases affecting the potato in New Zealand. It is equally prevalent on tomatoes. Introduced into a crop usually by means of infected tubers, given favourable conditions, the mycelium grows with the developing haulms, and if a relatively high humidity is present, the mycelium begins to produce fructifications. These are produced on the leaves as downy white patches, and in the course of a few days dark spots appear on the leaves. Should the fungus not be checked, the whole of the leaves and haulms may be converted into a black mass. The fructifications are in the nature of slender threads bearing flask-shaped structures from which are produced numerous *zoospores*. These spores are peculiar in that each is provided with two flagella by means of which they are enabled to swim in the moisture on the leaf. In this manner they may spread with rapidity over the plant, provided that abundant moisture be pre-

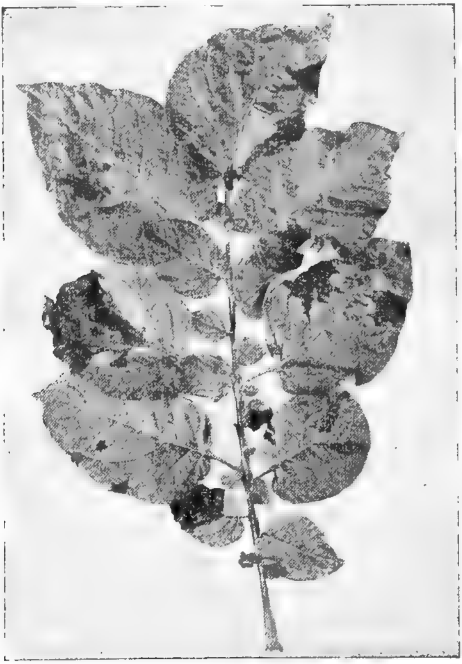


FIG. 112. *Phytophthora infestans* on leaves of potato

sent. They may be carried with wind and rain drops to other plants in the vicinity, and so rapid is their development, that in the course of a few days of high humidity the fungus may infect large areas. These spores may also be washed down to the soil, and penetrate to the tubers if such are lying near the surface. The disease is usually carried from season to season by means of infected tubers, so that it is evident one method of attack is to prevent tuber infection. In addition to causing tuber infection in the manner described by means of zoospores, the mycelium of the fungus often grows down the haulms and passes to the tubers; or in extreme cases it may pass from tuber to tuber in the soil. Even after tubers have been lifted, infection is possible in the bags, unless these are stored under dry conditions.

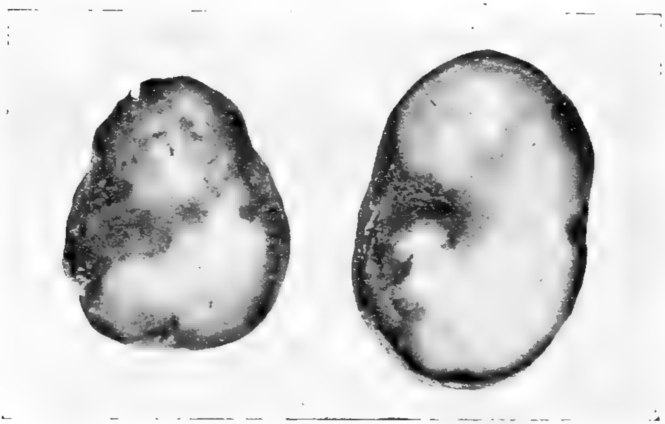


FIG. 113. *Phytophthora infestans* on potato tubers

We have here an example of a disease being spread by means of a latent mycelium in the tuber. Consequently control measures should be directed towards preventing infection of the tubers. It has been found that only a small percentage of tubers are normally infected at the time of planting, consequently even when diseased tubers are planted, it is possible to prevent any considerable infection of a field by covering the developing plants with a suitable fungicide. For this purpose bordeaux mixture or bordeaux substitutes have proved effective, provided the covering is thorough and frequent. In dry seasons, or in dry localities, it has often been found that spraying is unnecessary since, as has been shown, the fungus is able to fructify only in conditions of relatively high humidity.

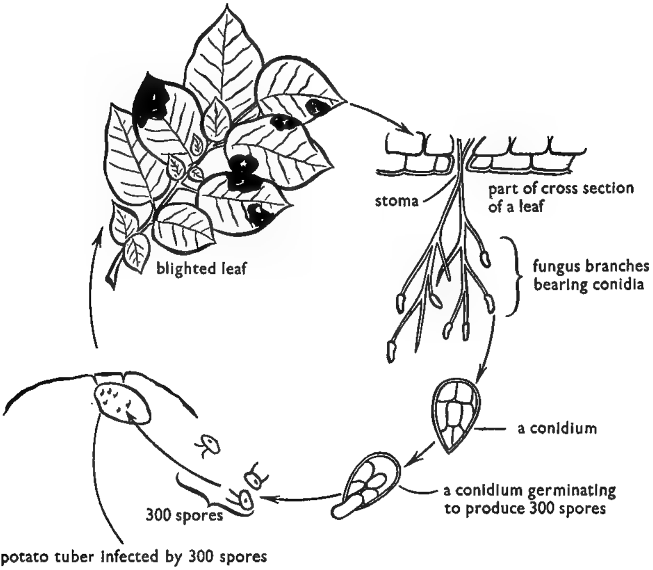

blighted leaf
stoma
part of cross section of a leaf
fungus branches bearing conidia
a conidium
a conidium germinating to produce 300 spores
300 spores
potato tuber infected by 300 spores

FIG. 114. Life cycle of potato blight (*Phytophthora infestans*)

Exercise 2.—In the late spring watch potato plants for dark spots on their leaves. Select affected leaves showing white mouldy growth and examine for fungus fruiting bodies. Examine also tubers old and new for the presence of blight.

(2) CLUBROOT (*Plasmodiophora brassicae*).—So serious is clubroot disease in brassicas such as turnips, swedes, rape and cabbages that it interferes with the growing of these crops in most parts of the Dominion.

The causative organism, *Plasmodiophora brassicae*, produces large irregular swellings on the roots of the host plant, hence the common name, clubroot. These gradually decay and cause the death of the plant, or under conditions of slight infection, may seriously impair its water supply, leading to wilt and gradual starvation.

In the malformed tissues the organism produces innumerable one-celled spores, each surrounded by a thick wall. These spores are compacted together in masses, and, when portions of the host decay, are liberated into the surrounding soil. Here, under favourable conditions, each germinates and produces a minute zoospore, which is armed with a single flagellum, and is consequently able to swim about in the soil moisture. Should a spore come in contact with the roots of some suitable host, it penetrates directly through one of the root hairs, and within the tissues divides repeatedly until numerous spores are produced. These fuse to form a *plasmodium*,

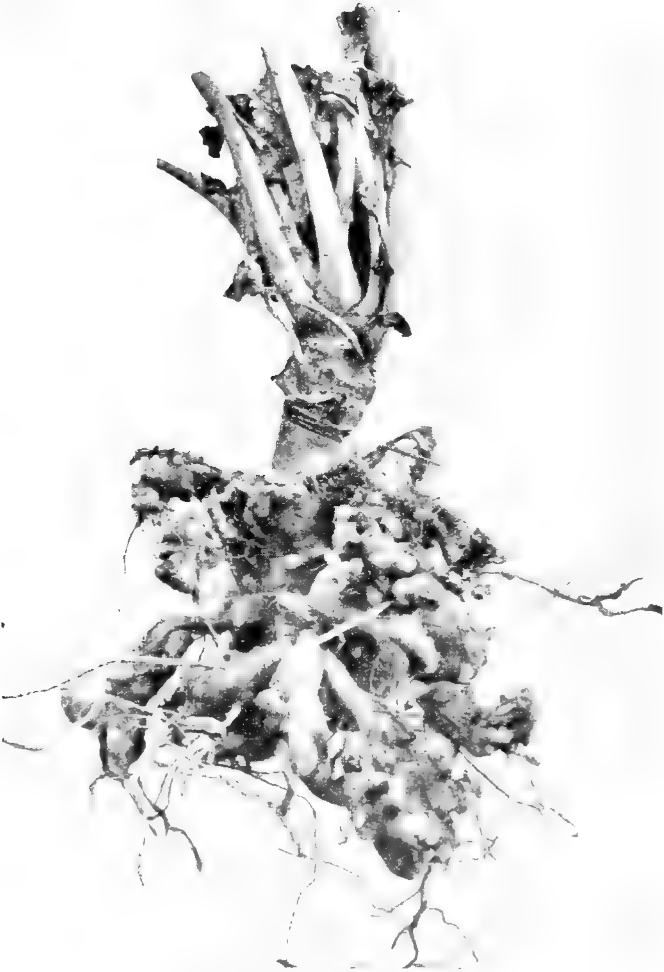


FIG. 115. Clubroot on rape

a mass of protoplasm with many nuclei and no cell walls. The plasmodium apparently stimulates the host to excessive cell production until the hypertrophied tissues characteristic of the disease are produced. Ultimately the plasmodium, which continues to increase in size during the proliferation of the host cells, becomes divided into innumerable small fragments, each of which becomes enveloped within a thick wall, and finally assumes the condition of a resting spore. In this condition it may persist in the soil for several seasons, and it is this power of remaining in the soil for several seasons, in a latent condition, which has rendered it a difficult disease to combat. The spores are also carried in the dung of cattle and sheep which have been feeding on diseased roots.

From the fact that the organism is able to infect its host plants only if the soil acidity in the vicinity is relatively high, a practical method of control has been worked out. If the land is limed at the rate of ½ to 2 tons of burnt lime or hydrated lime or 2 to 4 tons of ground limestone per acre or 1 lb. of hydrated lime per sq. yard, three months in advance of sowing the crop, and if the crop is sown with an alkaline fertiliser such as basic slag or an equal mixture of superphosphate and lime, only a small percentage of infection results, even on severely infected land. Further, if this treatment is followed on the same land for several consecutive seasons, a decrease in infection will be noted each season.

Here then we have an example of a soil-borne disease which may be effectively combated because of its known intolerance towards an alkaline reaction of the soil.

FUNGUS CLASS B, ASCOMYCETES (*Sac Fungi*)

During the life history of ascomycetes spore [illegible] produced, each ascus containing ascospores, commonly eight in number. (See diagram.)

The ascomycetes class is the largest of all the classes of fungi.

Examples are:—(1) *Venturia inequalis* causing Black-spot of apples; (2) *Podosphaera leucotricha* causing Powdery Mildew of apples; (3) *Sclerotina sclerotiorum* causing disease in lupins and many other plants, and (4) *Pseudopeziza trifolii* and *P. medicaginis* causing leaf-spot of clover and lucerne respectively.

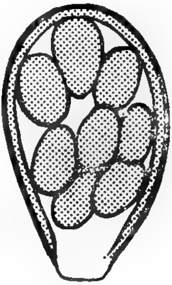


FIG. 116.
Ascus with eight ascospores

(1) Black-spot of Apples (*Venturia inaequalis*).—With perennial crops such as fruit trees, owing to the permanent nature of the crop, their diseases can be combated effectively only by a combination of orchard hygiene combined with the use of suitable chemical sprays. Sprays will not satisfactorily control the mycelium of a fungus. They must be directed against spores. Pruning will remove shoots infected with mycelium. In the example chosen this is well illustrated. This fungus overwinters in part within the fallen leaves on the ground. There it produces flask-shaped receptacles within which are formed club-shaped asci each containing eight ascospores.

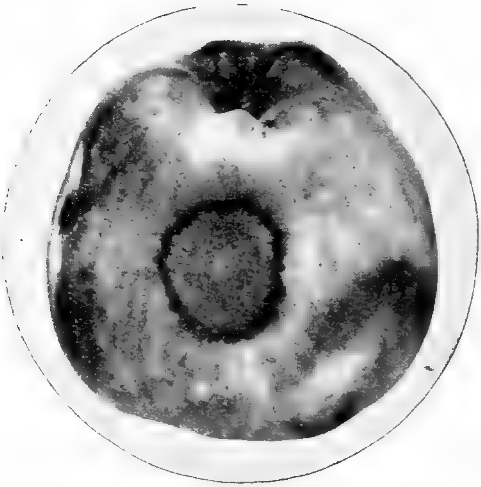


Fig. 117. Apple black-spot

In the spring spores are discharged from the fungous receptacles and infect developing leaves and fruits. This is the chief means by which this disease overwinters, under our conditions at least, though the fungus has been found overwintering on twigs. On leaves and fruits a conidial stage is produced, which produces black spots on leaves and fruits, hence the common name.

Knowledge of this life history has been made use of in working out a control programme. For it is now the practice to apply in advance of the spore discharge from the fallen leaves (it having been found impracticable to prevent this discharge by destruction of these leaves) a suitable fungicide which, harmless to the tree, yet destroys spores which may alight thereon. The usual practice is to apply one or two bordeaux sprays, the first at green tip (when leaves are just beginning to appear), the second at pre-pink (that is just as the first blossoms are beginning to show). These two foundation sprays are followed by others at intervals of three or four weeks. For summer sprays, it has been found preferable to use lime-sulphur plus colloidal sulphur, or one of the newer organic fungicides since these at suitable strengths are less liable to damage developing fruits which in the earlier stages are very intolerant of sprays and russet readily. The sulphur sprays have the added advantages of combating successfully certain insect pests, and in addition powdery mildew, which cannot be combated with bordeaux mixture.

Success in the control of a disease of this type is obtained only when trees are kept covered in an effective manner with suitably chosen fungicides.

(2) POWDERY-MILDEW OF APPLES (*Podosphaera leucotricha*).—This fungus, in New Zealand at least, overwinters by means of resting mycelium enclosed within the buds and bud scales of the young wood formed during the previous season; and by means of the older mycelium which persists in dense mats on tips of infected shoots. From these, during the spring months, conidia are produced in quantities, and if carried by wind or insects to developing leaves and twigs, may cause infection. The spore germinates, and produces the usual infection hypha. This does not penetrate the tissues, but remains on the surface and sends suckers or haustoria into the cells. Thus with the exception of these suckers, the fungus is entirely superficial. The mycelium develops and branches to form a dense weft, which covers the growing leaves and shoots with a white down. Sometimes a second spore form is produced, but this is so rare as to be negligible, the fungus persisting, as has been said, by means of the persistent perennial mycelium. The most effective controllant of this and other powdery mildews is sulphur in finely divided form, colloidal sulphur mixed with lime sulphur.

Onion 'mildew', which is a downy mildew, not a true mildew, is most effectively treated by the use of bordeaux mixture, plus summer oil plus a wetting agent.

(3) SCLEROTINIA DISEASE OF LUPINS (*Sclerotinia sclerotiorum*).—Mixed with lupin seed are not infrequently numerous sclerotia of the fungus, which are so alike in size and general appearance to the seed that it is not possible to free the seed from

them by dressing through ordinary machinery. Consequently when lupin seed is sown, the fungus is sown with them. In the soil the sclerotia germinate and produce stalked cups (termed *apothecia*) which bear large numbers of sacs (*asci*) each containing eight spores. These are forcibly discharged into the air and are carried with wind to adjoining lupin plants. Here under favourable conditions these spores germinate (especially if dead leaves or similar plant tissues happen to be present, and if moisture is abundant) and produce a mycelium which penetrates the tissues. A stem canker may be formed and cause death of the lupin plant; or penetration of the seed pods may take place. In either case the mycelium is aggregated into compact masses to form sclerotia, which during threshing are liberated and mixed with the seed.

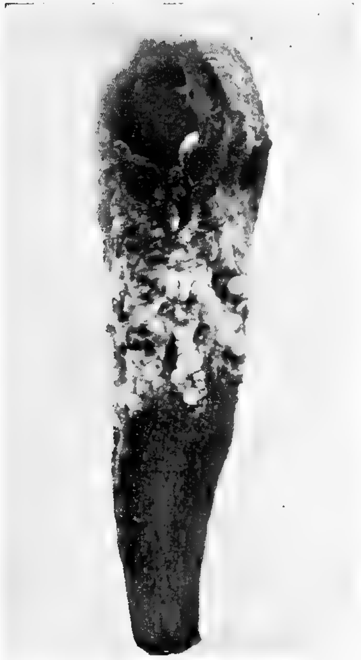


FIG. 118. Sclerotinia disease on carrot

Here we have an example of a disease being carried with the seed. As mechanical dressing is impracticable, it is evident that seed from clean lines should be used, if this disease to is be avoided. However the significance of contaminated seed must not be exaggerated. Wind-blown spores may be a far more common source of infection.

This fungus is unusual in that it attacks a great many plants, as beans, peas, lupins, sunflowers, artichokes, carrots, tomatoes, potatoes, lemons, and apples in store, and many others, including common weeds such as thistles.

FUNGUS CLASS C, BASIDIOMYCETES (*Club Fungi*)

All members of this class produce spores on a special structure called the *basidium*. (See diagram.)

Prominent in this class are the smuts and rusts of cereals and other plants.

Examples are:—(1) *Tilletia caries* and *T. foetens* and (2) *Ustilago tritici*, all causing smut in wheat; (3) *Puccinia coronata* causing rust in oats; and (4) *Stereum purpureum* causing silverleaf in peach trees and other fruit trees. The common mushroom is placed in this class also.

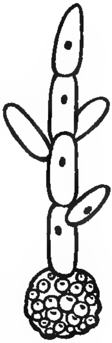


FIG. 119.
Spore germinated to form a four-celled basidium producing basidio-spores

(1) STINKING SMUT OF WHEAT (*Tilletia caries* and *T. foetens*).—This disease is caused by two closely related species of the smut fungi, so called because at maturity they convert the interior of the grains into a black smut-like mass. This mass is seen to consist of innumerable spores when examined under the microscope. Each spore on germination produces a short structure termed a *basidium* or a *promycelium*, which bears numerous conidia.

A conidium on germinating produces a short infection hypha, which penetrates into the host tissues where, under favourable conditions, it gives rise to a mycelium. Now in the species under consideration the spore balls are broken during threshing operations, and the seed is liberally dusted with them. Should such seed be sown, the spores germinate and produce conidia, which in turn produce each an infection hypha. This penetrates the seedling wheat plant and produces a mycelium which grows with the developing plant. until the seed head is in process of formation. The mycelium then penetrates the developing ovary, and converts this to a mass of mycelium, which ultimately produces the masses of spores which characterise the smut.

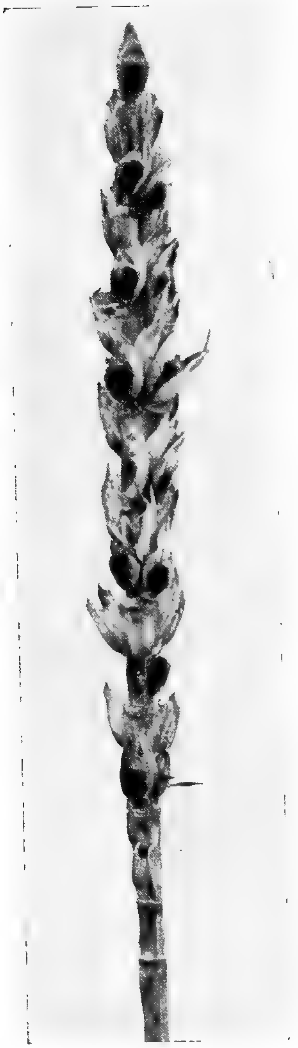


FIG. 120.
Stinking smut of wheat

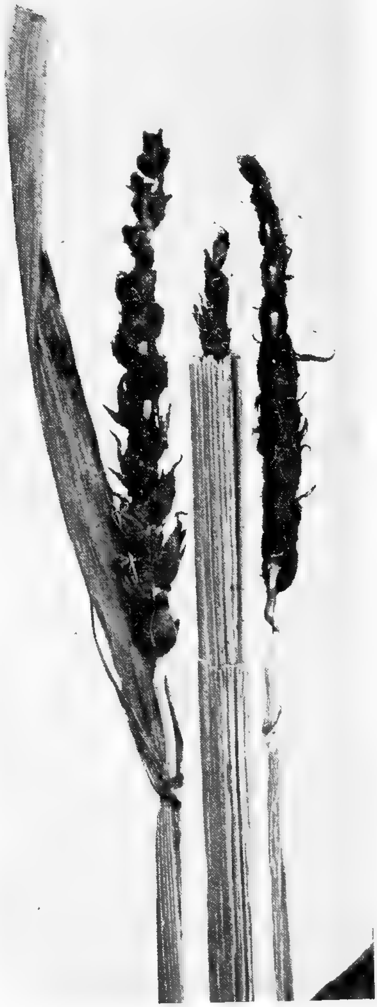


FIG. 121. Loose smut of wheat

The significant features of the life history of these closely related species, and one which enables successful control measures to be carried out, is that the spores are carried with the grain, and germinate about the same time as the wheat grain begins to germinate. It has been found that the spores may be destroyed readily with copper carbonate, or organic mercurials. The process is described later in this chapter. Control can also be secured by the hot water treatment.

(2) LOOSE SMUT OF WHEAT (*Ustilago tritici*).—This smut fungus differs from the preceding in several particulars. Infection of the wheat plant occurs at blossoming time, spores being carried by wind from infected to healthy plants. The spores germinate and send into the developing ovary an infection hypha which develops to form a mycelium. This remains in a latent condition, so that there is nothing to show whether such grains are infected or clean. Should grains carrying a latent mycelium be sown, the fungus develops at the same time as the seedling wheat plant, and grows with it until the ovary is formed. This is entered and converted into a mass of mycelium, from which at flowering time masses of spores are produced. These are usually dispersed by wind and infect other developing wheat plants in the vicinity.

With this smut, it is seen that it is carried from one crop to the next by means of a latent mycelium buried within the grain of wheat. Consequently chemical treatment of the exterior is useless. But research has shown that the fungus may be destroyed within the seed by steeping in hot water for a specified time. If properly carried out, this treatment will control the fungus to such an extent that clean lines may be secured.

(3) CROWN RUST OF OATS (*Puccinia coronata*).—The rust fungi are among the most difficult to discuss, as most of the economic species have complicated life histories. The species under discussion, which produces crown rust of oats, does not differ in this respect, for it is what is termed an *heteroecious* species (that is, it requires two different hosts, widely different botanically, upon which to complete its life cycle) and consists of numerous races or strains which exhibit towards different host plants a marked degree of selective parasitism.

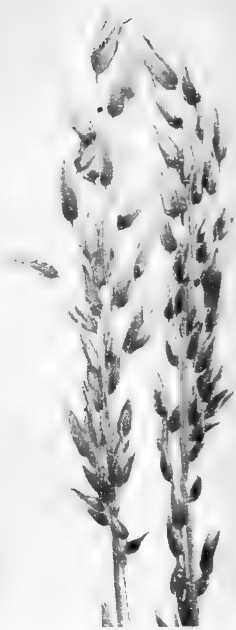


FIG. 122. Smut of oats

In Europe the life history is such that resting spores from oats produce in the spring the cluster-cup stage on buckthorn (species of *Rhamnus*). The spores produced from these cluster-cups in turn infect oats and produce first conidial spores (termed *uredospores*) and ultimately resting or overwintering spores termed *teleutospores.* In New Zealand the cycle differs in that the cluster-cup stage is not produced. Consequently the teleutospores have become functionless, so that we are led to suppose the rust is perpetuated by means of the conidia alone. But as in many localities, oats are grown for but a short period of the year, it does seem possible that the rust is able to carry on from one season to the next in this manner alone. As the same rust occurs on wild oats, and especially on Yorkshire fog and the various species of ryegrass, it is probable that the rust carries over from one season to the next on these grasses. If this is so, then we have an example of perpetuation by means of host plants, those which are useful and also those which are not, that is weeds. Unfortunately this host situation precludes effective control measures being made operative, since it is not practicable to remove any of the plants enumerated from the vicinity of the oat crop. Consequently in combating rusts of this type, we are forced to the production of varieties of oats which are resistant to the rusts in question. Several promising lines have been produced overseas. The Algerian variety is grown extensively in New Zealand because of its resistance to this rust.

Exercise 3.—When rust appears on oats or on a garden plant such as broad beans and hollyhock, select a specimen of the infection and examine under a magnifying glass. During the winter examine rust on weeds such as groundsel and useful plants such as ryegrass and barberry. Make a list of plants on which you have observed rust.

(4) SILVER-LEAF (*Stereum purpureum*).—This disease is caused by a fungus which penetrates the branches of peach, plum, apple, and numerous other fruit trees. Here it gradually becomes established and affects the tree by producing a toxic substance, which, carried to the leaves, so alters their structure as to make them appear as if silvered. This alteration prevents the leaves functioning in a normal manner, so that the tree gradually dies from starvation. The disease is significant in that it is able to penetrate into the tree only through wounds caused by removal of branches during pruning or by other causes. Use of this knowledge is made in working out a means of control, for if these wounds are protected with a wound covering as soon as made, entry of the fungus is not possible. Consequently it is the practice in progressive orchards to paint all wounds in branches more than one year old, with bitumen paint. Wounds in young shoots are usually impervious since the tree forms a protective barrier of wound gum, which effectively prevents such organisms from entering and becoming established.

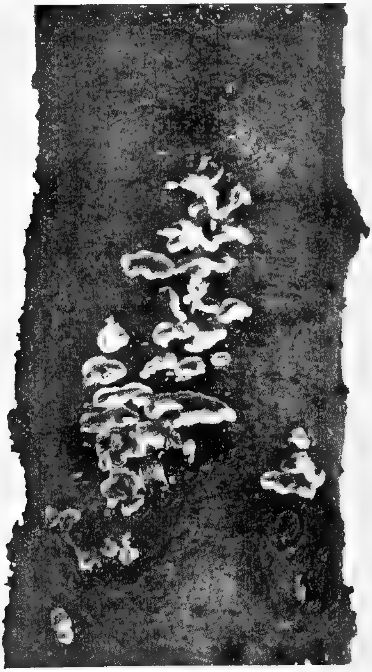


FIG. 123. Silver-leaf disease on peach

The fungus produces its fructifications on trees that have been killed in this manner. These are shelf-like in structure and bear on their lower surfaces the numerous spores. The latter are discharged and carried by wind to trees in the vicinity, where should any alight on wounded surfaces, they may germinate and penetrate in the manner described. It is not possible to combat the disease by removing these fructifications, for the fungus is so abundant on poplar, willow, and broom plants in the vicinity of most commercial orchards through the Dominion, that destruction is quite out of the question.

To Isolate Fungi

Exercise 4.—(i) Prepare potato dextrose agar, transfer it in 15 ml. lots to test-tubes, sterilise the tubes and their contents, and pour each test-tube lot into a sterile petrie dish being careful to avoid exposure of the agar. (See the appendix.) Rinse specimen material (soil or part of a diseased plant) in 50 to 70 per cent alcohol for two minutes, wash in distilled water and transfer pieces of the material to agar plates. Leave the inoculated plates at room temperature (or preferably at 20° to 24° C.) until fungus colonies appear. Place a little of the fungus on a microscope slide, macerate and mount in water or in glycerin. Examine under the low power of a microscope.

(ii) Take a small piece of diseased plant tissue, macerate it in a drop of stained lacto-phenol (see the appendix) on a microscope slide. Cover and examine under the low power of a microscope. Distinguish between: plant cells, fungus mycelium and fungus spores.

BACTERIAL DISEASES

There are far fewer plant diseases caused by bacteria than those caused by fungi. Microscopic in size and similar in structure to bacteria causing human disease and animal disease generally, bacteria causing plant diseases can be controlled in ways similar to those used against fungi causing plant diseases.

Fireblight (*Erwinia amylovora*)

The principal hosts of Fireblight are apple, pear, hawthorn, and cotoneaster. Symptoms are shown in all aerial parts of the plants, flowers, fruit, leaves and branches, attention usually being drawn to the presence of the disease by a few branches wilting at the tips and then turning brown as if scorched. With closer examination there may be seen dark-coloured, oval cracks or cankers from which often exudes a sticky slime teeming with the causative bacteria. Insects attracted to this slime carry the bacteria to the flowers which die from the infection. If fruit is formed, it also becomes infected and soon decays.

As the bacteria causing this disease are right inside the affected parts, external application of therapeutants is useless. To prevent the disease from spreading, affected branches should be sawn off, well below the signs of infection, and burned. The Fireblight Prevention Act, 1922, requires all hawthorn growing in a fruit producing district to be kept well trimmed or cut down.

To Isolate Bacteria

Exercise 5.—(i) Prepare nutrient agar in a similar way to the preparation of potato dextrose agar. Before pouring into four sterilised petrie dishes, add to each dish a few drops of one of the following:—(a) a soil suspension, (b) a suspension of plant material likely to be infected with bacteria, (c) milk, and (d) sputum. Then pour warm, liquid agar into each dish rotating on the bench to mix the material with the agar. When the agar has solidified, invert the dishes and keep them near the temperature of human blood or better at 35° to 37° C. Observe the nature of the bacterial colonies.

(ii) To make a bacterial smear:—Transfer with a sterile needle material from a colony to a drop of distilled water on a microscope slide. Gently dry the slide, stain with methylene blue (see the appendix) for 1 minute, wash off the surplus stain, and dry with filter paper. Adding a drop of cedar-wood oil, examine for bacteria with the oil immersion lens of a microscope. (After using an oil immersion lens, remove it from the microscope, dip in xylol and rub clean with a silk cloth.)

(iii) After pouring two dishes of nutrient agar and leaving to cool, cough into one and leave the other as a control. Invert the dishes and keep them warm for a few days. Compare the two dishes. Make a smear, as in (ii) above, and look for bacteria under an oil immersion lens.

VIRUS DISEASES OF PLANTS

Wherever leaves show abnormal twisting or rolling (leaf roll, crinkle), abnormal markings, especially mottling of colour, light green and dark green (mosaic), and wherever flowers show streaking of colour (streak), then virus disease is likely to be present. Stunting, accompanied by low production, is a usual additional symptom of virus infection. Many farm crops, notably potato and turnip, vegetables such as tomato, cucumber and cauliflower, and flower plants such as dahlia and tulip are subject to virus disease.

Transmission and Control of Virus Diseases

Present in the sap of plants the infective agent called a virus is transmitted from infected plants to healthy plants either by contact of one plant with another, by contact with tools and materials used with infected plants and left uncleaned, or by grafting, but the main mode of transmission is by sucking insects chiefly aphids. Rather interesting it is to know that before tending tomatoes a smoker should wash his hands because the mosaic of tobacco produces the disease in tomatoes. All these facts point to the control of virus diseases being possible only by indirect methods. Being present in most cells of an affected plant they are out of reach of therapeutants; transmission by contact demands proper hygiene during cultural operations; transmission by aphids calls for either destruction of the aphids (which may be impracticable) or for propagating plants, subject to disease, in surroundings naturally or artificially free from aphids, or for breeding plants resistant either to virus or to aphids. As virus diseased plants seldom recover from the disease and are a source of infection of healthy plants nearby, a further important means of control of virus disease is the removal and destruction of virus infected plants.

VIRUS DISEASES OF POTATOES

Two kinds of virus disease of potatoes, namely leaf roll and mosaic, have already been discussed. (See Chapter 19.) A third kind of potato virus called *severe mosaic* will be referred to here.

The inability to see virus with an ordinary microscope makes it difficult to know which virus is concerned in a particular virus infection. Moreover the recognition of a virus by symptoms is complicated. This is shown by the following facts about potato viruses.

(1) When a growing potato plant becomes infected during growth by virus, there are seldom any symptoms of the infection, but a plant grown from an infected tuber does show symptoms.

(2) Different varieties of potato differ in their symptoms of infection by the same virus. Thus one variety open to infection may resist infection and so cannot show any symptoms; a second may be infected but shows no symptoms; a third may show prominent symptoms, and a fourth may be severely affected.

(3) The same variety of potato growing under different conditions may show different symptoms with the same virus.

(4) More than one potato virus may infect a potato plant, generally producing more severe symptoms than when only one virus is present.

There are three important mosaic viruses called for simplicity A, X, and Y. Virus X is carried by most potatoes, but because it usually produces only mild symptoms, it may not be recognised. Nevertheless, it has been shown to reduce yield appreciably, in one trial, by 20 per cent. Transmission of virus X is by contact only between plants and by infected tubers. Viruses A and Y are both transmitted by aphids as well as by contact and by infected tubers, and the one produces somewhat similar symptoms to those of the other.

Severe forms of mosaic result when more than one of these viruses infect a potato plant. Viruses X and Y acting in unison produce *rugose mosaic* with prominent mottling, wavy leaf margins and dwarfing. Viruses A and X in unison produce *potato crinkle* showing crinkling of the leaflets and a dwarf, bushy plant habit.

TURNIP MOSAIC

Spread mainly by the grey cabbage aphid (*Brevicoryne brassicae*), Turnip Mosaic has the following symptoms:—On swedes the leaves are crinkled and mottled with only slight differences between the light and the dark areas. Sometimes there are dark-green, blistered areas. Infected plants as a whole are stunted, their stem-roots are small and their leaves tend to die off prematurely. On turnips the symptoms are similar but usually more pronounced.

A similar strain of mosaic called *Cauliflower Mosaic* has different symptoms. On cauliflowers and swedes the first symptom on young leaves is a lightening of colour along the veins called *vein clearing*. As the leaves grow older the vein clearing may persist but is usually replaced by dark-green bands of tissue beside the veins called *vein banding*. The growth generally is stunted. With cauliflowers the heads are small and of poor shape. On turnips the early symptoms of infection are yellow spots which may be followed by small dead patches along the fine veins. There often is a general stunting of growth and twisting and crinkling of leaves.

In controlling these diseases the following lines of action may be taken:—(1) Because at present there are no resistant varieties of turnips available, less dependence should be placed upon turnips and more upon swede varieties, such as Calder and Sensation, which are resistant, and upon chou moellier and kale which are also resistant. These resistant crops should be sown earlier than usual.

(2) Sowing of turnips later than usual to avoid the main aphid infestations.

(3) Spraying the turnip crop to kill aphids if the aphid infestations have begun to build up.

(4) Because the rape crop is often the host for carrying over virus-carrying aphids from winter-utilised brassicas such as kale and chou moellier to new season turnips, spraying of the rape against aphids may help to protect the oncoming turnips. Suitable chemicals for the spraying are lindane and metasystox, the latter, however, needing very careful handling. (See the next chapter.)

(5) Using the aphid-resistant variety of rape rather than susceptible varieties so that the host-chain of virus-bearing aphids may be broken at the rape 'link'. Thus both the numbers of aphids and the amount of virus disease transmitted would possibly be much reduced.

DEFICIENCY DISEASES OF PLANTS

Parasites are not the only cause of ill-health in crops. Soil deficiencies, as discussed in Chapters 11 and 13, also give rise to diseases which are usually referred to as deficiency diseases. Some of the more common of these diseases occurring in New Zealand are brown-heart of swedes, internal cork of apples and whiptail of cauliflowers.

BROWN-HEART OF SWEDES

Also called mottled heart, this disease is due to a deficiency of the element boron in the soil.

Like some other deficiency diseases, brown-heart develops commonly where continuous cropping is practised, i.e. it is due usually to induced deficiency in a soil. Especially is the disease likely to be induced if heavy liming is carried out for prevention of the fungus disease, club-root.

Showing little by way of external symptoms brown-heart is indicated mainly inside the stem-root by central, irregular areas of brown woody tissue. Broadcast applications of borax to the soil at the rate of 10 lb. to 20 lb. to the acre before or just after sowing the swede seed will prevent brown-heart. Where the deficiency is of a moderate to low order, borated superphosphate is effective. As borax in contact with swede seed is likely to injure the germination, provision must be made for sowing the seed separate from the fertiliser. Continued use of borax, especially at the higher rates, may lead to toxicity troubles.

Internal cork, or browning near the core, of apples is also due to soil deficiency of boron.

In cauliflowers a disease called *Whiptail,* in which the leaves are distorted, narrow and strap-like is usually due to soil deficiency of molybdenum. Most cases of this disease are prevented by the application of sodium molybdate up to 1 lb. per acre or of molybdenised superphosphate. As with boron and all trace elements, continued use of sodium molybdate, especially at the higher rate may lead to toxicity troubles fairly quickly. Deficiencies of nitrogen, magnesium, manganese and zinc also occur in New Zealand orchards.

PHYSIOLOGICAL DISEASES

Another set of diseases which are due not to parasites but to some unfavourable factor in the environment associated with the breakdown of cells are called physiological diseases. Because the cause of a physiological disease is usually related to climate, control of the disease is often difficult or impossible. Two common examples of physiological diseases are bitter pit of pip fruits, and blossom end rot of tomatoes.

CONTROL OF PLANT DISEASES

The saying, 'prevention is better than cure', applies most forcibly to plant diseases. When, for example, a parasitic fungus has become established on its host, the fungus is often deeply embedded in the host's tissues and so out of reach of curative measures. If a disease is to be kept in control, it is necessary therefore that measures be taken before the disease becomes firmly established. Further, as we have already noted with the diseases discussed in this chapter, control measures vary according to the nature of the life history of the disease, and depend for their efficiency upon their ability to break the life cycle of the disease.

The principal control measures are:—

(1) Clean cultivation to eliminate weeds and crop residues which act as carriers of disease from one crop to the next.

(2) Treatment of seeds, bulbs and corms with hot water or with chemicals to kill the fungus either on or within the plant.

(3) Soil treatment to reduce or eliminate soil conditions favouring parasites.

(4) Practising such rotation of crops that soil-inhabiting parasites are starved by withholding from the soil crops susceptible to the parasites.

(5) Prohibiting imports of plants, seeds and fruits likely to introduce serious diseases into New Zealand, and quarantine for all imports of plants and seeds. (See a later section in the next chapter.)

(6) Protecting plants by spraying and dusting.

PLANT PROTECTION

When other methods of controlling plant disease fail or are impracticable, recourse can often be had to plant protection. Because sprays and dusts are expensive and also are usually unpleasant and may be dangerous to use, it is essential that the plant husbandman diagnoses the disease correctly, chooses the correct materials and prepares them accurately, and applies them before the disease has become established.

As most plant protecting chemicals are dangerous to human beings, they should be stored in a safe place especially out of reach of young children, and empty containers of the chemicals burned or otherwise destroyed. Regard should be paid to the health of the spraying operator who should take precautions to ensure his health by avoiding inhaling the chemicals, wearing protective clothing, and washing the clothing and the exposed parts of his body after spraying. Regard should be paid also to the consumer of treated produce by ensuring that there is no spraying within the recognised safety period between the last spraying and the probable earliest consumption. Special precautions should be observed with those insecticides which are organic phosphorus compounds, viz. HETP (hexone), TEPP, parathion, schradan, demeton, and mipafox. (See the next chapter.)

FUNGICIDES

A fungicide is a chemical used in the control of parasitic fungi.

In discussing stinking smut of wheat it was shown that an effective control lay in dusting the seed with copper carbonate or organic mercurials. Dusts are used at the rate of 2 oz. per bushel. A machine of some type is necessary, a simple one consisting of a box or barrel with a tight-fitting lid mounted on trunnions so that it can be turned like a churn to bring seed and dust in contact.

It should be noted that the dust is an irritant poison which, when inhaled, causes nausea and vomiting. Consequently it is advisable to use a dust mask or damp sponge when working with this material.

HOT-WATER TREATMENT

This treatment, it will be remembered, is recommended for control of loose smut of wheat. It is equally effective as a controllant of stinking smut of wheat, loose and covered smut of barley, and both smuts of oats.

The procedure recommended by the Plant Diseases Division of the Plant Research Bureau (for loose smut of wheat) is to pre-soak seed for 5 or 6 hours in cold water (temperature ranging between 55° and 65° F.); to dip for 10 minutes in hot water held exactly at 127° F.; to cool and dry as rapidly as possible. For barley smuts a similar treatment is recommended, save that the dip is curtailed to 5 minutes. For oat smut, seed is immersed without pre-soak for 10 minutes in water held at 131° F.

Success is possible only if temperatures are maintained exactly as specified, so that an accurate thermometer is necessary.

BORDEAUX MIXTURE

This is perhaps the most efficient fungicide known for general purposes. It is of little value against powdery mildews, however, and should generally be replaced for summer purposes in the orchard and garden by colloidal sulphur, zineb and captan, which in most cases are less toxic towards foliage. Quinones such as phygon can also be damaging to some plants such as peaches and apples.

Bordeaux mixture is prepared by combining bluestone (copper sulphate) and hydrated lime (calcium hydroxide) in certain proportions.

Two formulæ are recommended, termed the winter formula and the summer formula respectively:

WINTER FORMULA:

5 pounds copper sulphate, (or 6½ oz.)

4 pounds hydrated lime, (or 5 oz.)

50 gallons of water (this can be reduced to 40 gallons without detriment), (or 4 gal.)

SUMMER FORMULA:

3 pounds copper sulphate, (or 4 oz.)
4 pounds hydrated lime, (or 5 oz.)
50 gallons of water, (or 4 gal.)

Mix the lime with water to the consistency of a thick cream, then add this to the copper sulphate dissolved in the rest of the water.

BORDEAUX SUBSTITUTES

These are now used extensively on tomatoes and include a group of sprays essentially different from bordeaux mixture and are not to be confused with so-called bordeaux powders. Two types of bordeaux substitutes at present certified by the Plant Diseases Division consist of copper oxychloride and copper oxide. The former is a blue powder containing 50 per cent of copper and the latter is red-brown in colour and also contains 50 per cent of copper.

Bordeaux substitutes are more expensive and less efficient as fungicides than bordeaux mixture but cause less injury to the foliage of certain crops. By using higher concentrations effective control of disease on tomatoes and potatoes can be obtained with improved vigour of growth and increased crop yield. These compounds are easy to prepare and do not leave such conspicuous spray residues as bordeaux mixture.

Dilutions vary with conditions but in general 5 lb. to 100 gallons of water is satisfactory for outside spraying and 3 lb. to 100 gallons for glasshouse crops.

LIME-SULPHUR

This is generally used on fruit trees as a summer spray in place of bordeaux, since it is not so liable to cause injury to fruits, and has the added advantage of being an insecticide.

A commercial product, lime-sulphur should contain 15 per cent calcium poly-sulphides. It is used in strengths varying according to the type of tree to be sprayed, and the time of the year the application is being made. Consequently no general recommendation can be made covering strengths. When trees are dormant, it may be used at 1-15 and will then control both fungi and pests such as scale; at pink and blossom fall, it may be used at 1-150; and during the summer from 1-150 to 1-180.*

* Those desirous of using this material, and other spraying materials also, are advised to consult the Orchard Instructor of the Department of Agriculture for the district as to strengths and times of application.

Lime-sulphur, however, damages the foliage of fruit trees, notably apricots, and causes some fruit blemish. Both of these types of damage may be of little moment in a home garden, but in commercial orchards they are important. Hence much use is now being made in commercial orchards of modern chemical sprays which do little or no injury to fruit trees. These sprays have their own defects, viz. they are effective only on a narrow range of diseases and many of them cannot be mixed without losing their effectiveness or causing damage, so making several separate sprayings necesary. Thus we have dichlone (phygon) for controlling the blossom-blight stage of brown-rot of peaches; and captan for brown-rot of peaches throughout the rest of the season, for black-spot of apples, and as a general fungicide for apples and pears.

Lime-sulphur is of little value in combating diseases of potatoes or tomatoes; for these, bordeaux mixture or the newer sprays should be used. As with fruit trees the newer sprays are more specific and less damaging than bordeaux. Thiram controls grey mould of tomatoes, nabam and zineb (dithanes) control late blight of tomatoes and potatoes and leaf mould of tomatoes, and salicylanilide (shirlan) controls leaf mould of tomatoes.

COLLOIDAL SULPHUR

Almost harmless to most plants, colloidal sulphur can be applied at any time of the year. It is the most effective spray known at present for the control of most of the mildews, and will also control mites to some extent. As it does not need water for its action, it is specially valuable against mildews during dry weather. Applied at the rate of 4 pounds per 100 gallons of water, colloidal sulphur is a satisfactory controllant also of rusts of vegetables and flowers and black-spot of apples.

Captan (trichloromethylthiotetra hydrophythalimide) is a very useful fungicide. In particular captan is effective against brown-rot of stone fruits, leaf spot of strawberries, and rusts.

The *carbamates* (ferbam, thiram and nabam, and zineb) and the *quinone,* dichlone, are all promising fungicides with special value in particular cases, some of which have been mentioned above.

BACTERICIDES

A bactericide is a chemical used to control parasitic bacteria. Bordeaux mixture and dichlone are effective against bacterial spot and bacterial canker. The antibiotic, *streptomycin,* controls blast of stone fruits.

READING

Elements of Agriculture, (Chapter XIV), Fream. Rev. by D. H. Robinson

N.Z. Journal of Agriculture, Aug. 1958, p. 125; Aug. 1957, p. 111; July 1955, p. 81; June 1955, p. 563; Feb. 1955, p. 115; Sept. 1951, p. 209

Rural Education Bulletin, Vol. 1. Nos. 2 & 3

Canterbury Chamber of Commerce Agric. Bulletin, No. 347

N.Z. Dept. of Agric. Bulls., No. 390, 'Disease and Pest Control'; No. 386, 'Health Aspects of Plant Therapeutants'; No. 20, 'Citrus Diseases'

Certification of Therapeutants and Plant Hormones, N.Z. D.S.I.R. Information Series, No. 13

Microbiology, An Introduction, E. Grey

Plant Protection in New Zealand, Atkinson *et al.* (1956)

Plant Virus Diseases in N.Z., Chamberlain, E., D.S.I.R. *Bull.* No. 108 (1954)

The Storage of Apples and Pears, Padfield, R. A., D.S.I.R. Bull. No. 111 (1954)

Trace Element Deficiencies of Fruit Crops in N.Z., Bollard, E., D.S.I.R. *Bull.* No. 115 (1957)

FILMS

(The National Film Library)

'Life Cycle of Pin Mould'
'Potato Blight'
'Brown-rot'
'Story of the Apple'
'Orange Grower'
'How Plant Breeding Helps the Farmer'

FILM STRIPS

'Penicillin'
'Man's Microbe Enemies'

24

Pests of Plants

BEFORE Europeans came to New Zealand there were few species of mammals, there was little cultivation of crops and there were few pests of plants. While birds and insects were numerous and there were a few reptiles in the form of lizards including, on some offshore islands, the famous tuatara, the only land mammals were two kinds of bat and the Maori dog and the Maori rat. With the advent of Europeans the balance of Nature became greatly upset. Much of the vegetation was consumed by fire, and birds became greatly reduced in numbers by the loss of their food, by the preying of introduced dogs, cats and rats and by shooting. Introduced mammals, chiefly sheep and cattle, throve well on good pastures, but wild pigs and wild goats became pests. Crops and pasture gave a greatly increased food supply to native and introduced insects which responded by increasing enormously in numbers. Birds, notably the sparrow, introduced to check the insects, tended themselves to become pests, chiefly of grain crops. Mammals such as deer, rabbits and opossums, introduced for sporting purposes, have become serious pests, especially as causative agents of soil erosion. (See Chapter 16.)

Man, having upset Nature's balance and wishing to produce his requirements from the soil at a higher and more consistent level than that found in uncontrolled nature, now finds he must attempt to achieve an artificial balance of natural forces. One important part of this attempt takes the form of a system of artificial control of pests. Included in this pest control system, which is continually being revised and developed, are:—special farm and garden cultural practices, the breeding of resistant plants, the use of some kinds of animals and of diseases to check pests, and the application of poisonous chemicals to reduce pest populations.

The animal kingdom, to which pests belong, is divided into nineteen great groups, the simplest being one-celled units of protoplasm called the protozoa, but only nine are of importance in agriculture.

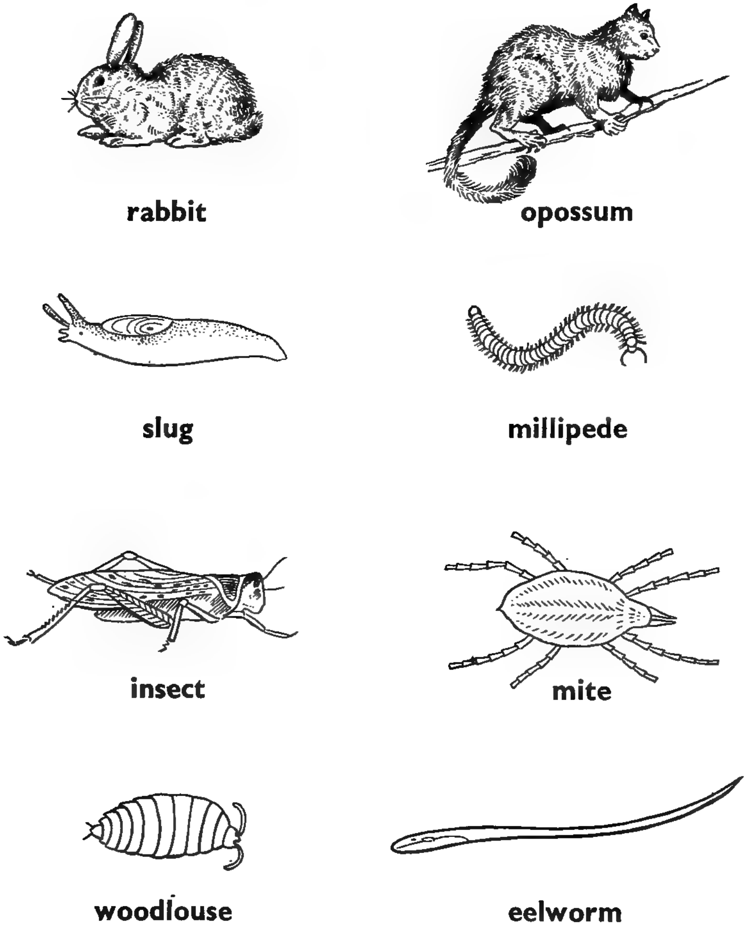


FIG. 124. Miscellaneous examples of plant pests

These nine in ascending order of organisation are: (1) the protozoa, including many parasites of man and domestic animals; (2) the flatworms, e.g. the liverfluke and tapeworms; (3) the nematods or roundworms, e.g. sheep stomach worm, and eelworms; (4) the nematomorpha or gordian worms, some of which are parasitic on insects; (5) the acanthocephala, including parasites of vertebrates; (6) the annelida or segmented worms, e.g. earthworms; (7) the arthropoda or animals with jointed skeletons, e.g. crayfish and insects; (8) the mollusca or animals often with limy external skeletons, e.g. mussel and snail; and (9) the vertebrata or back-boned animals, e.g. fish, frogs, reptiles, birds, opossum, sheep and man.

Of these nineteen great groups of the animal kingdom only four include plant pests of importance in agriculture, namely: the Nematodes or roundworms, including eelworms; the Mollusca, including slugs and snails; the Arthropoda, animals with jointed external skeletons, including insects, mites, millipedes and wood-lice; and the Vertebrata including opossums, wallabies, rabbits, hares, deer, pigs and goats.

That most pests of plants are insects is not surprising when it is realised that, numerically, nearly four-fifths of the animal kingdom consists of insects. So important are insects that a whole science concerned with the study of insects, called *entomology,* has developed. Hence in this chapter most of the examples of plant pests given are insects.

STRUCTURE OF INSECTS

The body of an insect is built up of a series of segments which are grouped into three well-marked portions:

(1) The *head,* consists of six segments. It bears the eyes, mouth parts, and antennae.

(2) The *thorax* consists of three segments, each of which bears a pair of legs, while in addition the second and third segments carry each a pair of wings.

(3) The *abdomen* lies behind the thorax, and may consist of as many as eleven segments.

Insects do not breathe through their mouths but through openings called *spiracles*, situated on the sides of the thorax and abdomen, and leading to chitinous tubes ramifying throughout the body.

THE LIFE CYCLE OF INSECTS

The life cycle of an insect involves change of some kind, usually *metamorphosis,* i.e. the changes of form an insect passes through to become an adult. It may have stages such as egg, larva, nymph, pupa, and adult or imago. (See Fig. 127.)

The Egg.—The eggs, which vary much in appearance, are generally deposited in contact with, or near to, a supply of food, which nourishes the young insects after they emerge from the eggs. As the tough, inelastic skin of the young insect will not allow a gradual increase of size, from time to time the distended skin splits and is shed, a process called the moult or *ecdysis*. Immediately after ecdysis there is much expansion of all parts of the body and the insect rests until the new skin toughens and hardens. The number of moults varies in different insects, some have 2 or 3, others 6 or 7.

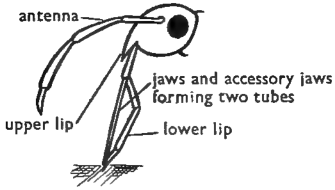
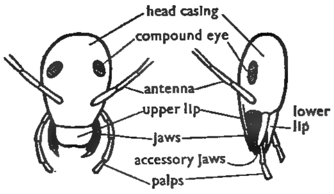


FIG. 125. The mouthparts of an aphis in the act of piercing a plant
(*After Doull in 'Rural Education Bulletin'*)



top view side view

FIG. 126. Head and mouthparts of a chewing insect

According to the amount of change an insect undergoes in its life cycle, it may be assigned to one of the following three types:—

(a) *Ametabola*. Those insects with no metamorphosis, only a development of the reproductive system, e.g. springtails.

(b) *Heterometabola*. Metamorphosis with these insects is incomplete. The young stages strongly resemble the adults in body form, type of mouthparts, and possession of compound eyes. They are called *nymphs*. Aphids, thrips, and grasshoppers are heterometabalous.

(c) *Holometabola*. The young stages in the metamorphosis of these insects (complete metamorphosis) differ from the adults in body form, mouthparts, and the absence of compound eyes. They are called *larvae*. Belonging to this type are beetles, flies, moths, butterflies, weevils, ants, bees and wasps.

PUPA OR CHRYSALIS

This is an *instar*, i.e. a period between moults which bridges the gap between larva and adult. Fig. 127 (1).

ADULT OR IMAGO—

The term adult or imago is used to designate the fully-matured insect. Fig. 127 (2, 3, and 5).

In general it is during the larval stage that an insect is most voracious, and hence most destructive.

MOUTHPARTS OF INSECTS

From the point of view of agriculture there are two main kinds of mouthparts in insects, the biting and chewing type and the piercing and sucking type. Biting and chewing mouthparts are present for example in beetles, earwigs and grasshoppers and in the larval stage of many kinds of insects. Between the upper lip and the lower lip (see Fig. 126) there are two pairs of jaws which move horizontally in a scissor-like action, the upper or true jaws tearing off and chewing the food, the lower or accessory jaws helping the chewing.

In butterflies, mosquitoes, flies, bees, and aphids the mouthparts are adapted by form and arrangement for sucking liquids. The honey bee has a long sucking proboscis for gathering nectar and a pair of strong jaws for removing wax and cleaning the hive. With aphids the jaws take the form of long bristle-like tubes which lie in a groove along a long lower lip adapted for piercing the plant host and sucking the plant juices. (See Fig. 125.)

An understanding of the way in which an insect pest feeds is important in controlling the pest.

CLASSIFICATION OF INSECT PESTS

A broad and brief classification of insect pests is as follows:—

A. CHEWING INSECTS

(a) Caterpillars of moths and butterflies, e.g. Diamond-backed Moth (*Plutella maculipennis*), Magpie Moth (*Nyctomera annulata*), White Butterfly (*Pieris rapae*).

(b) Larvae of saw-flies, e.g. Pear Slug (*Caliroa limacina*).

(c) Adults and larvae of beetles, e.g. Brown Beetle and its Grass Grub (*Costelytra zealandica*).

B. SUCKING INSECTS

(a) Scale insects, e.g. Mussel Scale (*Lepidosaphes ulmi*), Cottony-cushion Scale (*Icerya purchasi*), and mealy bugs.

(b) Aphids, e.g. Woolly Aphid (*Eriosoma lanigerum*); Green Peach Aphid (*Myzus persicae*); Potato Aphid (*Macrosiphum euphorbiae*); Cabbage Aphid (*Brevicoryne brassicae*); Rose Aphid (*Macrosiphum rosae*), Grape Phylloxera (*Phylloxera vastatrix*).

(c) Thrips.

C. BORING INSECTS

(a) Caterpillars of moths, e.g. Codlin Moth (*Cydia pomonella*); Potato Tuber Moth (*Phthorimaea operculella*); the Subterranean Grass Caterpillars of the large night-flying moths (*Oxycanis* spp.); Tomato Stem Borer, the caterpillar of the small moth (*Gnorimoschema operculella*).

(b) Larvae of beetles, e.g. Wire-worms, which are the larvae of click beetles, and Citrus Borer, the larva of the native longhorn beetle (*Oemona hirta*).

A. CHEWING INSECTS

With mouthparts adapted for tearing off and chewing food, chewing insects are very destructive. Some eat every part of leaf and stem, others only the epidermis or the edges of, or holes in, the leaves. The Grass Grub eats the roots of grasses.

(1) DIAMOND-BACK MOTH (*Plutella maculipennis*).—The moth, which is a slender greyish insect, has a wing expanse of about three-eighths of an inch. The fore wings are slaty coloured with pale yellowish white triangular markings on the posterior edges. When the wings are folded these pale edges come close together and form diamond-shaped areas—hence the popular name. The moth, which is plentiful from January to April, appears of a uniform brownish-grey tint when flying, the diamond mostly being noticed only when the insect is at rest with wings folded.

The larvae of the moth devour the leaves of cabbages, turnips, and other crops and weeds of the cabbage tribe.

The larvae, which are at first grey and then green, develop from eggs which were deposited on the underside of the leaf. They taper towards both ends, have 16 feet, and a black head, and are about three-eighths of an inch long when full grown.

The eggs which in early summer are laid on the leaves of various cruciferous weeds, and later in the season on crops such as turnips, swedes, cabbage, hatch in about 5 to 6 days, but the time varies greatly according to temperature and humidity.

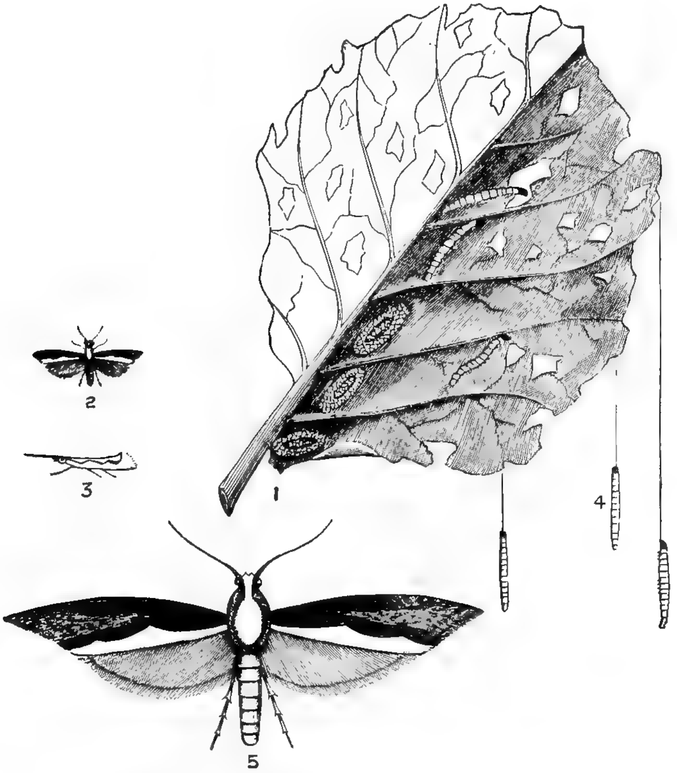


FIG. 127. Diamond-back moth. 1: Leaf of cabbage, much reduced, showing caterpillars and cocoons, natural size; 2: Moth, natural size, flying; 3: Moth at rest; 4: Caterpillars dropping to the ground when disturbed; 5: Moth (magnified)

The young larvae at first mine in the leaves, and after the first moult they feed on the leaf surface; if frightened they usually drop to the ground from the leaf, hanging by a silken cord which they use in regaining the leaf when the cause of the fright is past. The larval stage varies from 15 to 45 days, according to conditions of temperature and food supply, but in summer is usually from 14 to 17 days. The pupal stage, which is of 10 to 12 days' duration, is passed in a loosely spun, yellowish, silken cocoon placed on the leaf. There are about six or seven broods in a year.

To a considerable extent *Plutella* is now controlled in the field by larval and pupal parasites.

The pest is difficult to control directly. The fact that the larvae drop to the ground when frightened puts them under control to a certain extent, for if on the appearance of the pests, a cultivator with shrub or brush attached is repeatedly taken through the crop, the silken threads by which the larvae are suspended will be broken.

Eradication of cruciferous weeds is advisable.

Spraying in the field is expensive, and apt to be ineffective because of the difficulty of reaching with the spray the under surface of the foliage where the pest feeds. In the garden, dusting with DDT or spraying with arsenate of lead will be found most successful. Natural enemies are fungi, birds, and certain Hymenopterous insects.

(2) PEAR SLUG (*Caliroa limacina*).—The mature insect is a shining black sawfly about one-fifth to a quarter of an inch in length, with two pairs of semi-transparent wings which are about three-quarters of an inch from tip to tip when fully spread. This sawfly, which in early summer comes from the ground where it has passed the winter as a pupa enclosed in a dark, silken cocoon, cuts slits in the leaf and deposits eggs below the epidermis. Little white blisters or patches of white dead skin indicate where the eggs have been deposited.

In a few days small dark green slug-like larvae emerge and commence to feed on the upper surface of the leaf, the soft parts of which they devour, leaving the network of veins held together by the skin of the lower side which turns to a brown colour. These larvae mature in about 4 weeks.

When mature the larvae lose the slimy character and become dry and yellowish, and fall to the ground where they pupate, emerging as perfect sawflies in about 2 weeks. Several broods appear in a season.

The pest damages mostly cherry, pear, plum fruits and also the hawthorn. It can be controlled by spraying with arsenate of lead or DDT whenever the larvae are observed.

Hedges such as hawthorn or cherry-plum round orchards, should be avoided for these shelter the pest.

(3) The Grass Grub (*Costelytra zealandica*).—A good example of a native insect which has found increased supplies of food to its liking in improved pastures, the Grass Grub has in several districts increased in numbers to a high and dangerous level. The adult beetle, known as the Brown Beetle, together with its larva and those of allied species such as *C. smithi* and *C. striata* are responsible for extensive damage to pastures, cereals, root crops especially crucifers, fruit trees especially stone fruits, and ornamental shrubs.

The adult beetle of *C. zealandica* is brown in colour, with darker margins to the wing cases, and destitute of hairs except for brownish hairs along the side of the body, on the head, and across the front of the thorax, where they form an erect fringe just behind the head. The body is rather stout, broad, and blunt, and measures about three-eighths of an inch in length.

The adults are nocturnal in their habits, taking to the wing at dusk, their presence being detected by the droning sound they create during flight. After dark they alight and feed on the foliage of plants, at times causing considerable damage in orchards and gardens by defoliating the trees. In this respect the brown beetle is often confused with the bronze beetle (*Eucolapsis brunneus*), which, however, is a quite different species.

Large swarms of the brown beetle are on the wing during November, December and January, although odd adults may be observed at other times.

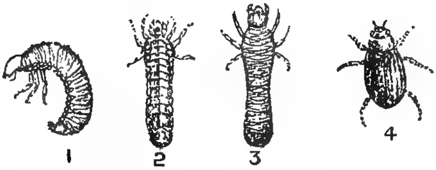


Fig. 128. Grass grub (*Costelytra zealandica*) 1: Larva, side view; 2: The same from below; 3: The same from above; 4: Adult beetle. (All natural size)

The female brown beetle lays her eggs at the base or among the roots of grass, just beneath the surface of the ground, and from these the young grubs hatch to commence their attack upon the plant roots. During late November a few young grubs may be found at work just beneath the surface of the ground, and by December and January they are extremely abundant. In

March a considerable number are half to three-quarters full grown. By May, all are three-quarters grown. Throughout the winter the grubs remain feeding close to the surface. By August most grubs are fully grown and in September and October they burrow to a depth of 4 inches to 10 inches in the soil and form earthen cells to pupate. The pupal stage occupies 4 to 6 weeks. By October most of the grubs have pupated and in the north of the North Island adults start to emerge in October.

The grass grub is creamy white in colour, with a brownish head, and lies in the ground doubled up in the shape of the letter U.

As the grubs feed mainly on grasses and cereals, this points to the value of crop rotations as a means of checking the pest.

Skim ploughing in February to March and subsequent thorough surface cultivation is very effective, because it exposes the grubs to the attacks of birds and to drought. The destruction of the vegetation also tends to starve the grubs, though they will survive for a considerable time on the remaining vegetation. However, the most effective means of controlling this pest is by applying DDT (100 per cent p.p.i.) at the rate of one pound per acre. This is usually carried out in conjunction with the autumn application of fertiliser by using DDT superphosphate.

B. SUCKING INSECTS

Symptoms of infestation of a plant with sucking insects include:—a general weakening and stunting of the plant, malformed leaves, and pale colour of the leaves. Often there is also a stickiness and blackening of infested plants due to these insect pests excreting 'honey-dew', a sweet, sticky substance on which grows black, sooty mould.

(a) *Scale Insects*:—Scale insects are so called because the female is protected by a scab-like covering. As a group, scale insects are of major importance because, unlike many other insects which attack only one group of related plants, they infest a wide range of plants. Scale insects show marked differences between the sexes. The males are usually of minute size, two-winged, and without any mouthparts, while the females are of large size, never winged, and possess well-developed mouthparts.

(1) MUSSEL SCALE (*Lepidosaphes ulmi*).—Found on apple, plum, pear, peach, apricot, hawthorn, willow and poplar trees, and on gooseberry and currant bushes, this pest's most common host is the apple tree.

The mussel scale is brown, from one-twelfth to one-eighth of an inch long, and not unlike a mussel-shell in shape. Under it is to be found usually a dried-up female and a cluster of creamy-white semi-transparent eggs which may number from 80 to 90. These eggs hatch out as soon as the warm weather sets in. The young nymphs, which are small and whitish in colour, crawl about over the bark for varying periods from a few hours to one or two days. Once having inserted their beaks into the bark they commence to secrete a waxy scale coating. When fully grown the males emerge as winged insects, and the females, after mating, deposit their eggs under their scales. As oviposition proceeds the female shrinks until only a very small insect is left.

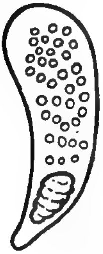


FIG. 129. Mussel scale (*Lepidosaphes ulmi*). Scale turned over, showing adult female and eggs

The scales are usually firmly fixed to the bark, and act as a shield to the eggs and to the insects which are to be found towards the narrow end.

A small parasitic wasp (*Aphelinus mytilaspidis*) attacks this scale to some extent. Those scales which show a small hole through which the adult parasite has emerged, are those which have been killed by the larvae of the parasite.

Effective control is usually achieved by spraying. Where a winter spray of lime-sulphur or red oil emulsion is not sufficient, a white summer oil should prove effective if applied at a time when the young scales are on the move.

(b) *Aphids*:—Also called plant lice and greenfly, aphids are among the worst of the plant pests. Few plants are free from their attacks. Living by sucking the juice of the plants which they have penetrated with their piercing mouthparts (see Fig. 125), they reproduce so rapidly that whole crops may be completely destroyed in a short time.

With soft swollen bodies of variable colour, they carry characteristically on the after surface of their abdomens a pair of short tubes pointing backwards and outwards—the *cornicles*. (See Fig. 130.)

Aphids are covered with a waxy protective substance in the form of a powder or woolly threads secreted by the cornicles. Besides providing general protection this substance causes water to run off them. Infestation by aphids often causes the leaves to curl in such a way that the insects are hidden inside them. The sticky 'honey dew' excreted by some aphids blocks up the breathing pores of the leaf and is a medium for the 'sooty' mould giving a blackened appearance to some plants and trees.

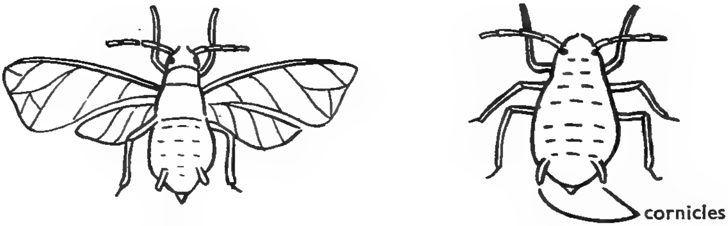


FIG. 130. Adult female aphids, wingless and winged. The adult male is similar but is always winged

Life Cycle of Aphids:—Although often having complicated life cycles aphids may be given a brief generalised life cycle to cover them all.

Two kinds of host plant provide homes for aphids during the year, a winter-resisting plant, usually a perennial or a woody plant, and a food plant in the growing season.

Wingless females overwintering on the host plant in the spring are peculiar in two respects. First, they show the phenomenon of *parthenogenesis,* that is, the act of reproducing without being fertilised. Second, they are *viviparous,* meaning that embryonic development takes place within the female. With aphids the females give birth to adults. These young feed on the juices of the plant, and in less than a week may also give birth to young; indeed, one aphid is capable of giving rise to several millions in a season, because of the great number of broods.

During the summer winged females are also being produced. These act as migrants which fly to the summer host plant and give birth to numerous young. With all females, parthenogenetic and viviparous, generation follows generation in rapid succession, wingless generations alternating with a winged generation, the latter flying to infest other plants.

In the autumn the males, which are winged, appear. Both winged males and winged females seek and fly to the winter host plants. There the winged females produce viviparously wingless daughters which mate with the winged males to produce fertilised eggs. The life cycle in thus completed with fertilised eggs overwintering on the winter host plants.

Hosts:—Many plants are attacked by aphids. Those commonly attacked are:—crucifers, beans, rose, peach, plum, apple, grape, cherry, currant, poplar and pine.

Aphids are recognised as the *vectors* or carriers of a group of serious diseases known as virus disease. (See Chapters 19 and 23.) Thus certain aphids, chiefly *Myzus persicae*, are known to spread such diseases of the potato as mosaic, leaf-roll and crinkle. The Cabbage Aphid (*Brevicoryne brassicae*) is responsible for the transmission of Turnip Mosaic. In fact aphids are now of considerable economic significance in crops which may not be commonly damaged by direct attack.

Control of Aphids:—Fortunately aphids have a large number of natural enemies, namely several kinds of insects and some birds, notably the sparrow. Ladybird beetles, their nymphs and larvae (*Coccinella* spp.), Lacewing larvae or aphis-lions (*Micromus* spp.), Hoverfly maggots (*Lasiopticus* spp.) and several other insects all devour many aphids, such useful insects being called *predators*.

Bad weather conditions, especially cold temperature, help to check aphids. Cold, wet spells in the summer keep down the reproductive rate and allow the natural enemies to keep abreast of the aphids. When the weather is hot and dry, however, the pests increase enormously, so that, unless a plant is of a kind or a strain resistant to the parasite, chemicals have to be brought into action. As aphids feed beneath the surface, stomach poisons like arsenate of lead are of no use so contact poisons or fumigants have to be used.

Of the chemicals, nicotine sulphate, with soft soap as a spreader, is one of the best, but is effective only in warm weather. Kerosene emulsion and white oil emulsion are good alternatives to nicotine with red oil emulsion for deciduous trees in the winter. For fruit trees and some farm and vegetable crops lindane (B.H.C.) is very effective. For certain flower plants and ornamental plants generally the organic phosphorus compounds, HETP, TEPP, malathion and parathion are specially useful, but great care must be taken in applying all of them, except malathion, as they are highly poisonous to human beings. In order to avoid destroying honey bees, lindane and the phosphorus compounds should not be applied to plants in flower.

The use of *systemic insecticides,* e.g. Schradan, is a promising line of attack on aphids. Sprayed on the plant or on the soil, systemic insecticides are taken in by the plant making its sap poisonous to aphids and other sucking insects. Schradan should be used only on ornamental plants. Chemical control of aphids is not easy mainly because (1) it is almost impossible to reach all the aphids on a plant, allowing the survivors to increase rapidly, and (2) winged aphids from elsewhere readily re-infest treated plants.

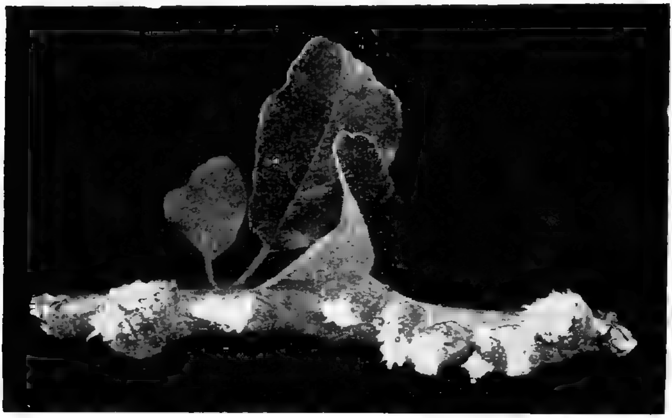


FIG. 131. Apple twig attacked by Woolly Aphis

(2) WOOLLY APHIS (*Erisoma lanigerum*).—Attacking apple, quince, pear, and hawthorn trees, Woolly Aphis indicates its presence by a woolly growth on the affected areas. Aphids generally establish themselves first on the new wood, for there they can easily pierce the bark with their beak-like suckers and absorb the sap of the plants. The puncturing of the bark induces the appearance of characteristic 'galls' on the twigs.

The aphids are pinkish yellow when young, changing to some shade of brown or grey later. The young insects often pass the winter in crevices in the bark.

Because the insects attack the roots as well as the stems of the majority of the kinds of apples, the difficulty of control is greatly increased, for though spraying may cope with the pest in the aerial portions, fresh infection may be caused by migration from below. However, certain varieties—and Northern Spy in particular—are not attacked by the pest.

Measures of prevention and remedy are:—

1. The use of blight-proof stocks (see Chapter 22).

2. The pest may be controlled by winter spraying with red oil emulsion—this should be looked on as the chief spray.

3. If the winter spraying has not been thoroughly effective, summer spraying with white oil emulsion or nicotine sulphate may be resorted to.

4. BHC is very effective, using the mixed isomers type in the dormant season and the lindane type in the growing season.

Fortunately this pest is now practically controlled by its parasite *Aphelinus mali,* a small wasp, which was introduced into New Zealand for this purpose. It affords an excellent example of *biological control,* though in some years the aphid gets away from the parasite.

C. Boring Insects

The larvae of these insects bore their way into plant tissues, usually fruit or stem. Those inhabiting pasture land take shelter during the daytime by boring into the soil. Thus for example the Subterranean Grass Caterpillar (*Oxycanus* spp.), where it has laid bare the soil by eating the pasture covering, shows emergence holes in the soil about the diameter of a lead pencil.

(1) The Codlin Moth (*Cydia pomonella*).—The attack of the codlin moth is the cause of the worm-eaten condition of fruit. Apples are very prone to attack, pears are sometimes much injured, and quinces, plums, peaches, and apricots are known to have been attacked.

The moth is of a general greyish-brown colour, and about three-quarters of an inch in spread of the fore-wings, on the tips of each of which is a distinctive round bronzy patch. It is, however, seldom seen because it lies concealed during the daytime.

Life Cycle:—Eggs are laid by the moth at night upon any part of the fruit, bark or foliage of the tree during the period November to February. The grubs which hatch from the eggs in from 10 to 14 days may enter the apple at the calyx or blossom end and burrow to the centre but more usually they bore through the skin of the apple. In doing this they throw out at the entrance hole dirty brown matter. As the grubs destroy the core the affected fruit frequently falls immediately.

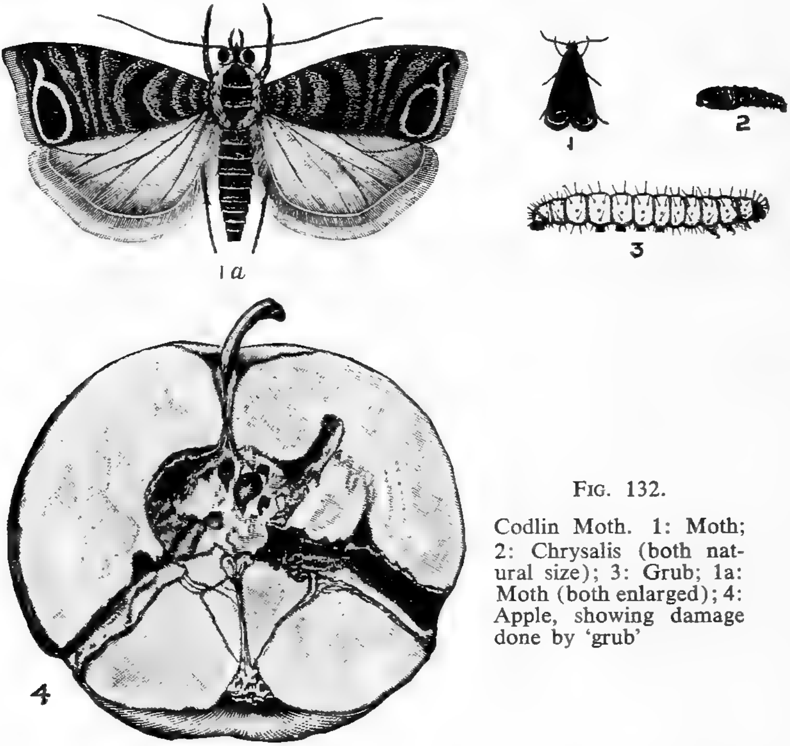


FIG. 132.

Codlin Moth. 1: Moth; 2: Chrysalis (both natural size); 3: Grub; 1a: Moth (both enlarged); 4: Apple, showing damage done by 'grub'

The larva when mature is somewhat more than half an inch long, and is of a pinkish-white colour. It has eight little black dots or warts on each segment, two pairs of these being on the back and one pair on each side. When fully grown it leaves the fruit by eating a fresh passage through the fruit to the side, this being completed in about four weeks from hatching. It then spins a fine silken thread by means of which it descends to the ground if the fruit has not already fallen. It immediately hides itself in loose bark or crevices, usually on the trunk of the tree. There it spins a cocoon of silk so mixed with bits of surrounding material as to provide a substantial shelter, and then changes into the chrysalis stage. From the chrysalis a second brood of moths may develop, but in most parts of New Zealand there is only one brood of any importance.

The insects remain hidden through the winter in the grub form, assuming the chrysalis state in late winter or early spring. They emerge as moths first in October and onwards to January and February.

Control.—The object should be to destroy all grubs before they enter the apple. The desired result may be attained almost with certainty by spraying with arsenate of lead (plus hydrated lime) or with DDT from petal fall in at least three sprays as follows:—

(a) Within 5 days after the petals have fallen—the object is to place a quantity of poison in the calyx cup before it closes up as it does about 10 days after the fall of the petals. As some of the young grubs enter the fruit through the blossom end they will eat some of the poison and succumb. Spraying when the bloom is on would result in poison being deposited in the calyx cup, but it is an undesirable practice, because the spraying material is prone to injure the pollen and to kill the bees and other insects whose visits are so valuable.

(b) A second spraying begun not earlier than 4 weeks and completed not later than 6 weeks from the fall of the petals.

(c) A third spraying carried out during the 10th week from the fall of the petals.

It should be noted that in some districts the pest has developed a high degree of resistance to arsenical poisons.

Other measures which may help in the control of Codlin Moth are:—

1. The removal of rough bark from the tree trunks where caterpillars may overwinter.

2. The banding of the tree trunks with scrim or corrugated cardboard to collect the caterpillars as they seek shelter. Later the bands are removed and destroyed with their tenants.

(2) THE POTATO MOTH (*Gnoroimoschema operculella*).—The perfect insect is a small, narrow, brown and grey moth varying from three-eighths to three-quarters of an inch in length. The larva is pinkish and about half an inch long when mature.

In the United States of America these insects are also referred to as the tobacco split worm, since the larvae commonly mine in the leaves of tobacco, and the burrows thus formed cause the leaves to split when used as wrappers for cigars. Potato, tobacco, tomato, and weeds of this family are all hosts for this pest.

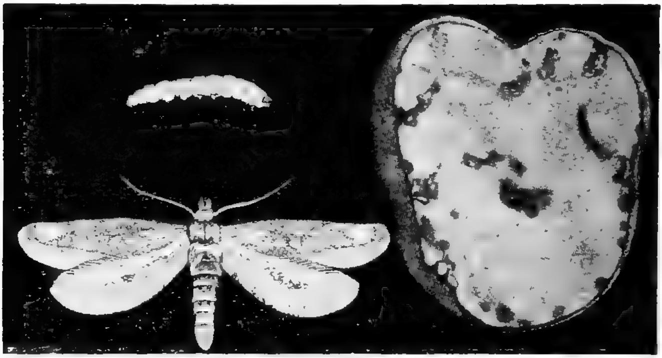


FIG. 133. Potato Moth (*N.S.W. Dept. of Agriculture*)

The eggs are soft white bodies just visible to the naked eye. They are deposited usually on the under side of the leaf or, in the absence of foliage, on the tuber where the eggs are crammed into the eyes or other depressions. On hatching the larvae mine in the leaves, and subsequently burrow down the stalk and destroy the young plant. On the tubers they mine deep into the flesh. When about to pupate the larvae seek a secluded spot, generally in the wilted tops. The moths of the later broods deposit their eggs on the potatoes themselves, which are liable to infestation whether left in the field or stored after being dug. If any tubers are not properly covered with soil they will be infested; this is especially likely to happen when potatoes are grown in heavy soil, which cracks and thereby exposes the tubers.

The control measures are:—

1. Thorough cultivation and 'hilling' to cover all tubers.

2. Collection and destruction of dead plants and small and discarded tubers. The former should be burnt, the latter may be boiled and fed to stock.

3. Old sacks, and other containers, which held infested potatoes should be dipped into boiling water.

4. Infested seed should never be planted.

5. Land where the moth was present the previous season should not again be used for potatoes.

6. The seed should be planted deeply and well covered.

7. The potatoes when dug should not be left exposed overnight in the field, and they should be stored so that moths cannot gain access to them to deposit eggs.

8. The mouths of the bags should be sown immediately upon filling, instead of leaving them exposed or covered with a mass of haulms which probably contain moths or caterpillars.

9. In the case of seed potatoes dusting the tubers with DDT powder as they are stored.

10. Destruction of weeds of the potato family such as Apple of Sodom and Nightshade which, apart from other undesirable characters, are liable to serve as breeding places for the moth.

Plant Pests Other Than Insects

Reference has already been made to the destructive nature of several introduced mammals notably rabbits, deer, wild goats, wild pigs and opossums. Under certain circumstances birds may become pests, but generally speaking birds are very useful in keeping down insect pests.

There are several kinds of less highly organised animals of small size some of which are similar in general form to insects. These include mites, slugs, snails, woodlice, millipedes and eelworms. The only example of these pests to be dealt with in detail in this chapter is Red Mite. Being pests usually only of the garden, slugs, snails and woodlice are best controlled first by practising good garden hygiene and second by using the appropriate chemicals. For slugs and snails a bait is used consisting of one ounce of metaldehyde powder mixed with three and a half pounds of bran. For woodlice dust the affected areas with DDT powder.

For millipedes disinfect seed or soil with lindane. Where eelworms infest the soil and roots, disinfection of the soil is the best practice; in bulbs and corms, hot water treatment; in leaves and stems use either parathion or the systemic, schradan, but both are very dangerous to use, and the latter should be used only on ornamental plants.

Mites differ from insects in that they possess four, instead of three, pairs of legs in the adult stage, there is no distinct head and there are no wings. While being closely related to spiders, mites differ from them in having no distinction between thorax and abdomen. All mites are of small size, some being microscopic, and some having mouthparts adapted to feeding on liquid food, in the case of plants upon the sap.

RED MITE (*Metatetranychus ulmi* and *Tetranychus telarius*).—Found on many kinds of fruit trees and garden plants, Red Mite sucks the sap from the leaves and the pores are closed by excreted matter. The punctured leaves dry up and appear sickly and brown. The mites vary in colour from light red to deeper red, and sometimes are green.

In spite of having no wings the pest does spread far, due to carriage mainly by wind, and by animals, and the farmer and his implements.

In the winter with heavily infested trees, the eggs, which are tiny, red and shaped like onions, form conspicuous patches on the bark. These eggs, laid in the late summer and autumn, hatch in the spring into young somewhat similar to their parents. Reaching the adult stage in about two weeks these new season adults lay eggs on the foliage. From spring to autumn several generations are thus produced.

The pest is most injurious in hot, dry weather.

Control:—To destroy the eggs overwintering on the bark is difficult but red oil emulsion, 5 per cent, helps.

In summer, white oil in two applications or lime-sulphur spray may be used.

Alternative summer sprays of greater effectiveness but more dangerous to the operator are the organic phosphates, HETP, TEPP, parathion and malathion. To protect the consumer of produce the latter two sprays should not be used within 4 weeks of harvesting time.

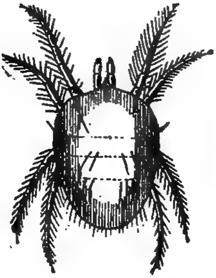


FIG. 134. Red mite (greatly magnified)

The spraying must be done thoroughly so that the material reaches both sides of the leaves where the mites are to be found in great numbers.

GENERAL METHODS OF CONTROL

Control of plant pests may be grouped under the following broad headings:—

1. *Chemical Control,* involving the use of:—
    - (a) Stomach poisons, e.g., Lead Arsenate, Paris Green (Copper acetoarsenite), Sodium fluoride, and Metaldehyde.
    - (b) Contact insecticides, e.g., Nicotine sulphate, Oil emulsion, Pyrethreum, Lime-sulphur, Derris, DDT, DDD, BHC, HETP, TEPP, Malathion and Parathion.
    - (c) Fumigants: Carbon bisulphide, Paradichloro-benzene, Hydrocyanic acid gas, Methyl bromide, Chloropicrin, Dichloropropene, and Ethylene dibromide.
    - (d) Systemic insecticides, e.g., Schradan, Demeton, Mipafox, and Metasystox.
    - (e) Repellents: Creosotes as applied to timbers, Oil of citronella.
    - (f) Ovicidal or egg-killing washes, e.g., Tar oil, and petroleum, (red oil and white oil).
2. *Control by Farm Practice.*
    - (a) Crop rotation.
    - (b) Tillage.
    - (c) Times of sowing, planting and harvesting.
    - (d) Use of fertilisers to encourage strong healthy growth.
    - (e) Use of plants resistant to insect attacks.
    - (f) Use of traps and bands.
    - (g) Farm hygiene.
3. *Biological Control.*
    - (a) Protection and encouragement of insectivorous birds and other insectivorous animals such as the hedgehog.
    - (b) Introduction and colonisation of beneficial parasites and predators.
4. *Legal Control.*
    - (a) Laws to enforce quarantine regulations at ports of entry in order to prevent the introduction of injurious insects. (See a later section.)

(b) Enforcement of certain spray and fumigation practices to control specific pests.

(c) Insecticide laws to prevent adulteration of insecticides.

CHEMICAL CONTROL

The most suitable chemical to use in the control of any given insect pest will depend of course on the type of insect with which we are dealing. In the case of mandibulate insects, i.e., those with chewing mouthparts, a stomach poison is probably most suitable. The method of attack is to spray the food plant of the pest with, say, an arsenical, so that the insect, when feeding, will ingest a certain amount of the poison with its food, and thus be killed. Examples of insects controlled in this way are the larvae of the codlin moth and the diamond-backed moth.

In the case of those insects with piercing and sucking mouthparts which are adapted for piercing plant tissue and sucking up the sap, a stomach poison would be of no value. Insects of this type may be controlled by means of contact insecticides such as nicotine sulphate or pyrethreums, or in the case of ornamental plants by the use of systemics such as schradan. Insects that may be controlled by this method are aphids, mites and young scale insects.

Insects which attack stored products such as cereals and foodstuffs, cannot be dealt with by either of the previous methods, hence the fumigation method of attack must be adopted. Common fumigants are methyl bromide and carbon bisulphide, common examples of insects controlled in this way being the granary weevil (*Calandra granaria*), and *Angoumois* grain moth.

Repellent insecticides such as creosote confer immunity from insect attack on timber. Further uses are found for repellent insecticides in treating stock to ward off fly attacks. A degree of immunity from mosquito attacks is conferred on human beings from the use of oil of citronella.

Contact insecticides affect insects in different ways. Nicotine sulphate, for example, damages the tissues; oil emulsions block up the breathing pores, while pyrethreum, which is the basis of fly exterminators used in so many homes, has the effect of paralysing the nervous system. Of the more modern insecticides, outstanding in value are the chlorinated hydrocarbons, mainly contact insecticides, DDT (dichlorodiphenyltrichlorethane), DDD (dichlorodiphenyldichloroethane), and BHC (benzene hexachloride). So effective are they, however, that they often kill not only the pests of plants but also beneficial insects such as honey bees, predators and parasitic wasps. To prevent loss of bees, the host plants should be sprayed only when not in flower, and special care must be taken to prevent spray or dust drifting to flowering crops and pastures and to beehives near by.

As a result of chlorinated hydrocarbons killing useful predacious and parasitic insects, the numbers of pests such as woolly aphis and red mite increase very greatly. To stave off this increase other sprays, most of them considerably more dangerous to human beings than the first, have to be brought into action. However, a 'silver lining to the dark clouds' may perhaps be provided by the systemic insecticides which, being absorbed by the plant, are toxic to sucking insects but are almost innocuous to chewing insects, to which class the useful parasitic and predacious insects belong. The systemic insecticide would kill the insect feeding on the plant, but would certainly not affect useful insects just landing on the plant.

Many of these modern insecticides have the additional disadvantage over the older ones of leaving on produce appreciable amounts toxic to human beings. Hence they should not be applied within three or four weeks of harvesting. However an old-established spray, lead arsenate, is similarly defective.

CONTROL BY FARM PRACTICE

1. Shelter for insects should be destroyed. Weeds and crop residues frequently serve as wintering places for pests, and, but for the shelter and sometimes the food which is thus provided, many serious pests would experience difficulty in surviving the period between successive crops of the plant on which they prey (e.g., potato moth, aphids of crucifers). By thorough weed and rubbish destruction, shelter, breeding places, and food supply would frequently be removed.

2. Rotations, if well arranged, serve to check insect pests, for many insects usually confine their ravages to a particular plant or class of plants. If these plants are not cultivated, obviously the insect pest will be deprived of its food supply, and will sooner or later disappear through starvation.

3. Sowing times and harvesting times sometimes may be arranged to avoid insect attack. For example cruciferous crops such as rape would be sown to avoid the main flights of the Brown Beetle; potatoes would be dug early if there is risk of infestation by the Potato Tuber Caterpillar.

4. Choice of kind of crop or variety of crop may help in the war against insects. Thus it may be possible to avoid using cruciferous crops if they commonly succumb to aphid infestations.

5. Farm hygiene also comes into the plant pest control picture. Used produce containers, e.g. potato sacks and apple cases should be cleaned and treated with either insecticide or boiling water. Bulky crop residues such as chou moellier stalks should be ploughed in deeply to prevent them being hosts for pests likely to infest subsequent crops.

6. Clean seed, bulbs, corms and tubers only should be used. Either they would be obtained from pest free regions or properly fumigated or steeped before use.

BIOLOGICAL CONTROL

It has already been mentioned that many pests of plants have their own natural enemies. In seeking to achieve a balance of his own in nature, man, especially the entomologist, makes systematic use of these natural enemies. As the poet Swift observed:—

> 'So, naturalists observe, a flea
> Has smaller fleas that on him prey;
> And these have smaller still to bite 'em
> And so proceed *ad infinitum.*'

The systematic promotion then of the enemies of pests to achieve a balance between host, pest, and enemies of the pest is what is known as biological control. However, as the quotation from Swift points out, scientists must take account of the pests of the enemies of the pests, that is, *hyperparasites*. Thus, when useful enemies of plant pests are being considered for introduction to a country, these hyperparasites must be excluded.

As far as biological control of plant pests is concerned, there are two main directions in which the balance of nature is upset, namely:—

(a) By the increased food supply for the plant pests native to the country. This has happened in New Zealand with the Grass Grub which increased enormously in numbers, helped by the fact that the pest has few or no natural enemies.

Wasps (*Thynnid* species), parasitic on similar grubs in Australia, have been imported with a view to controlling the Grass Grub, but have yet to prove successful.

(b) Insect pests, where accidentally introduced into a country, may leave their habitual parasites and predators behind them, so that there is every prospect of their rapid multiplication and spread. An example of this is the accidental importation of the White Butterfly (*Pieris rapae*) into the Hawke's Bay district. It is in cases of this kind that the artificial introduction of parasites should be undertaken. One of the best examples of the control of an insect pest by its natural enemy, a predator, is in the case of the control of the cottony cushion scale (*Icerya purchasi*) by the ladybird beetle (*Rodolia cardinalis*). The scale, when first introduced, spread very rapidly in California, causing enormous loss to the citrus orchardist; the introduction of *R. cardinalis,* however, retrieved the position. This scale was also introduced into New Zealand, but is well controlled by the same ladybird beetle.

Parasites live internally on only one individual, for example, *Aphelinus mali* on woolly aphid, referred to earlier. Predators, on the other hand, eat up other insects, often in large numbers, for example the larva of the eleven-spot ladybird will eat large numbers of aphids.

An outstanding example of biological control along novel lines is that carried out in 1954 in the small Caribbean Island of Curacao. There the screwworm fly was causing devastating losses of livestock. 'Entomologists reasoned that since the female screwworm fly mates only once, the male could be turned into a living insecticide by sterilising it with atomic radiation. The continuing release of hordes of sterile males would, with each generation, whittle down the screwworm population. Mating with the sterile males, these females would produce only infertile eggs. So, during the autumn of 1954, half a million sterilised males were released on Curacao. By January 1955 the screwworm fly had disappeared from the island.'*

Further kinds of enemies of insect pests are various diseases of insects, including viruses, bacteria and nematode worms. Although these disease organisms are not so obvious in themselves as insect parasites and predators, nevertheless their effects in keeping down the numbers of insect pests may be very obvious. The European Sawfly, for example, only a minor pest in Europe because it is kept in check there by a virus disease, was destroying much standing timber in Canada. Infected larvae of the Sawfly were obtained from Sweden and extracts from these containing the virus were sprayed by aeroplane over infested

---

* *The Readers' Digest.*

Canadian forests. The result was a 99 per cent kill of the sawflies. A virus is now being distributed in New Zealand for the control of white butterfly.

Fighting insects with insects and their own diseases often makes for effective control of pests with less danger than chemical poisons. This is apparent from two lines of evidence:—

(1) Several kinds of insecticides, notably DDT, tend to become less effective after a few years of use than when they were first used. This is due to the development of strains of insect pests resistant to the chemicals.

(2) Beneficial insects are often killed, along with the insect pests, by chemical sprays and dusts. Some of these chemicals, again notably DDT, have the added disadvantage that they are specific in their action, that is they kill only a narrow range of insect pests. The result is that pests like scale insects, aphids and mites build up in numbers because they are not harmed by the chemicals and their parasites and predators have been killed. So extra special sprays must be used to kill such pests freed from their enemies.

It should be noted that with biological control there is no hope of exterminating the pest, and often other methods of control must be used to supplement it. When a parasite becomes so abundant as practically to wipe out its host, then it too must suffer decline through lack of food supply. The scarcity of parasites now allows the host pest to increase until again overtaken by the parasite. Thus, under some conditions there will be irregular alternate periods of abundance and of scarcity of the pest.

PLANT QUARANTINE

In order to prevent the introduction of any more plant diseases and pests into New Zealand, there are strict plant quarantine laws. All imported fruit, vegetables, plants and seeds must be accompanied by certificates of health, and on arrival are subject to inspection and possibly fumigation. Complete embargoes are enforced against plant products likely to carry serious diseases, e.g. oranges from places with the oriental fruit fly. As soil attached to plants may harbour disease-producing organisms, no soil can be imported with plant material.

Although the wide seas surrounding New Zealand provide a good natural barrier against diseases and pests entering from other lands, man has broken the barrier, being responsible for bringing into New Zealand most of the diseases and pests we have. With the introduction of fast travel by sea and especially by air, and with the growth of the tourist traffic, the importance of man as a spreading agent has increased markedly. Consequently great vigilance must now be exercised to prevent the introduction of any more diseases and pests. This necessity for vigilance is specially apparent when we consider insect life cycles. The larva of an insect must be adequately fed to enable it to proceed to the next stage of its life cycle and the adult must have a suitable plant on which to lay its eggs if these are to hatch and the larvae are to survive. Hence the quicker the transport of plant material containing an insect at one stage or another of its life cycle the more likely is that insect to be capable of establishing itself in its new surroundings. Serious pests which could become established in New Zealand if vigilance were relaxed are many. Prominent examples are the Oriental fruit fly (*Dacus furrugineus dorsalis*) and the Colorado potato beetle (*Leptinotarsa decemlinata*).

Not only is plant quarantine imposed on plant products entering the Dominion but also sometimes between one part of the country and another, e.g. the Grape-vine Diseases Regulations, 1952, are meant to prevent the spread of the phylloxera insect which destroys the roots of grape-vines not grafted on to phylloxera-resistant rootstock. Places south of Tauranga are free from infestation by this insect. Under the regulations no grape-vines from places north of and including Tauranga are to be sent to places south of Tauranga unless they have a certificate showing that they have been sterilised under the supervision of a Horticultural Inspector of the Department of Agriculture.

Everyone should co-operate in trying to prevent any more diseases and pests becoming established in New Zealand. Both importers and travellers should be conversant with the plant quarantine regulations and carefully abide by them. If a disease or a pest slips through the quarantine net and threatens to become established, everyone should regard himself as part of an intelligence system for reporting the occurrence of the disease or pest so that measures for early eradication can operate effectively. Co-operation has an even wider application. Just as New Zealand requests other countries to treat against disease transmission certain plant products being exported to New Zealand so New Zealand undertakes to treat material exported from New Zealand. Thus, for example, potatoes shipped from California are washed completely free from soil which may carry disease, and flower bulbs which we send to Australia are, before being dispatched, fumigated to kill organisms of disease.

To sum up about the control of plant diseases and pests it seems that all forms of control must be used. Especially should chemical methods and biological methods work in one with the other, that is, they should be complementary rather than supplementary, so that one reinforces the other.

PRECAUTIONS WITH PLANT THERAPEUTANTS

Emphasis was laid in the previous chapter upon the necessity for great care being exercised in storing and using chemical sprays and dusts. As both fungicides and insecticides, especially the modern ones, are dangerous poisons, no apology need be made for repeating in this chapter the precautions which should be taken. The following list is that given by Dr. H. Jacks in the *N.Z. Dept. of Agriculture Bulletin,* No. 386.

1. Store materials in a dry, cool, and well-ventilated room. Make sure containers are tightly closed and properly labelled.
2. Store materials out of reach of children and animals.
3. Avoid spilling materials when measuring out and when charging sprayers and dusters. Clean up any spillage at once.
4. Defective containers should be handled with hands protected by natural rubber gloves to guard against absorption through the skin.
5. Chemicals spilt on the skin should be washed off immediately with soap and water. Clothing on which any material has been spilt should be removed and operators should wash with soap and water before changing. Drops or particles in the eye should be removed by flushing with large quantities of water.
6. Avoid contact of materials with mouth.
7. Always use eyeshields when spraying or dusting. Protective clothing and respirators should be worn when applying phosphate insecticides.
8. Avoid eating, drinking, or smoking during spraying operations and on or in the neighbourhood of the spraying area.

9. Allow adequate time between application and crop harvest to minimise residues.
10. Avoid spraying in windy weather to prevent damage to vegetation, people, and animals in the vicinity of operations.
11. Leave the spraying area if headaches, blurred vision, giddiness, palpitations, or tightness in the chest develop.
12. Prompt treatment is vital in most cases of poisoning and medical aid should be sought at once.
13. Dispose of unused material in the sprayer by discharging it in a safe place, for example, a hole in the ground filled after emptying the sprayer.

Exercise 1.—(a) Trap, kill and mount insects according to directions such as those given by the Auckland War Memorial Museum.

(b) Examine colonies of Woolly Aphid on apple trees and other trees for aphids parasitised by the small parasitic wasp, *Apelinus mali.* The parasitised aphids will be recognised by their lack of woolly covering and by being of a dark, purplish-black colour.

(c) Similarly examine Mussel Scale for parasitism shown in each affected scale by a small, emergent hole.

(d) In the summer examine aphid infested crop plants. Using a magnifying glass study the form of the aphids.

(e) With any diseased plant try to decide whether its diseased condition is due to attack by fungus, bacteria, virus or pest. If due to a pest, try to decide which kind of pest.

READING

Insect Pests, Cottier, W., *Plant Protection in N.Z.*, Pt. 5

N.Z. Journal of Agriculture, current articles on the Home Orchard, the Home Garden, the Flower Garden, Seasonal Notes and Current Research Items; Apr. 1958, p. 367; Jan. 1957, p. 11; Dec. 1956, p. 606; Mar. 1954, p. 263; Apr. 1953, p. 305; Oct. 1953, p. 371; Sept. 1951, p. 195; Aug. 1951, p. 113; May 1951, p. 409; Apr. 1950, p. 337.

Rural Education Bulletin, June 1956, Aug. 1955, Feb. 1952.

Canterbury Chamber of Commerce Agric. Bull. Nos. 348, 329, 265, 241.

N Z. Dept. of Agriculture Bulletins, Nos. 390, 386, 385, 363, 314.

Certification of Therapeutants and Plant Hormones, D.S.I.R. Information Series, No. 13.

FILMS

(The National Film Library)
'Codlin Moth'
'Apple Aphis'
'Point of Danger'

25

Pruning

In studying this chapter reference should be made to 'buds' in the latter part of Chapter 3.

Pruning may be defined as the training of plants by cutting away parts of them. The objects of pruning are:—

(1) To control the form of the plant to allow of cultivation as close as possible without injury to the limbs, and at the same time to permit of easy spraying and gathering of the crop.

(2) To stimulate the production of regular crops of good size and quality.

(3) To help to control disease.

(4) To counteract as much as possible unfavourable climatic conditions. For instance, to avoid wind damage it is generally desirable to have low trees bearing their fruit close to stout limbs. Again, in hot climates it is desirable to have a good cover of foliage over the framework of the tree to avoid sun-scald of the limbs.

Facts of Plant Life Underlying the Practice of Pruning

1. Within certain limits *the greater the vigour of a tree the less will be its tendency towards fruit production.* Soil conditions, fertilising, and various other causes may result in vigorous growth. When this occurs the production of fruit will be lessened, and will increase again only from a quiescent condition of the plant or the particular branch under notice.

2. *The vigour of a shoot increases according as the shoot approaches the vertical position,* for sap flows most freely towards the highest points. This fact can often be observed on fruit trees by comparing the growth of two corresponding shoots one of which has assumed a vertical direction and the other a horizontal direction. When such shoots are compared it will be noted that the horizontal one makes less growth than the vertical one, but has a greater tendency to develop fruit buds.

3. The *vigour* of a plant or portion of a plant is *largely governed by the amount of leaf surface,*—this is to be expected seeing that the leaves are the breathing, the assimilating, and the main transpiring organs. This fact is of particular importance in operations, such as summer pruning, which influence the leafage.

4. *The fewer buds on a branch the stronger will be the growth from each individual bud.* A definite amount of sap containing readily available plant food is diverted into each branch for the development of buds thereon, and when the number of buds to share the sap is reduced the amount available for each is increased, and the growth made from each is correspondingly affected. On these facts depends the practice of considerably reducing the top shoots when vigorous growth is desired: the buds which remain utilise an extra volume of sap and so their development is hastened.

5. Usually the topmost shoot appropriates the most sap and makes the most growth. This fact explains the appearance of so-called 'robber' shoots, i.e., topmost, upright shoots which receive more than their share of sap outgrow the others and upset the desirable symmetry or 'balance' of a tree. Such robbers can be controlled by suitable measures such as pinching or removing the growing point during the active season to reduce their vigour. Frequently other strongly growing shoots, known as 'water sprouts', appear early in the summer, lower down on the branches. They are the results of a disturbed flow of sap and their formation depends upon the vigour of the plant and the severity of the pruning.

6. The checking of growth induces a fruiting habit. This is the fact underlying the practice of root pruning which is at times employed successfully on trees which produce an excessive amount of wood growth and very few fruit buds. Checking of growth may also be caused by such practices as bending, twisting, and notching of shoots.

The fact that a decrease in vigour of a plant, so long as it remains healthy, induces the fruiting habit is in accordance with the plant's aim to reproduce itself. The decrease in vigour is, as it were, interpreted as a sign of approaching death, and so in order to fulfil the reproductive process flowers are borne and fruit set. Success in pruning depends primarily on being able to maintain the desired amount of vigour which is indicated by a certain balance between the vegetative activity and the fruiting habit. As trees vary individually in their constitution and vigour it is obvious that no rule of thumb can be laid down for pruning.

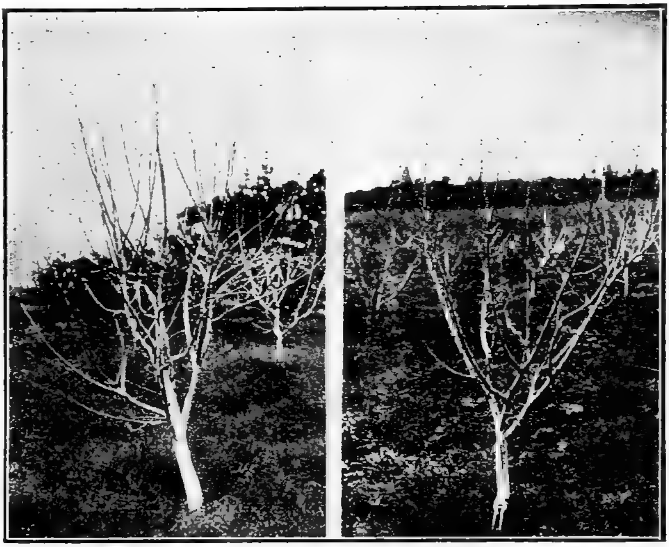


FIG. 135. *Left*: Not summer-pruned; *Right*: Summer-pruned. Note the spur development and the production of only the few strong leaders which are necessary for the building of the framework

TYPES OF PRUNING

1. WINTER PRUNING

Carried out when the wood has ripened and the foliage fallen from deciduous plants, in general it is the most important form of pruning. It consists mainly in the removal of branches or shoots—a work which is best done at this season, for foliage being absent, the position of all growth can be distinctly seen, and the future development and value estimated. The effect of winter pruning is the forcing of vigorous growth when the dormant season is past. Therefore, it induces wood rather than fruit production, and so is of service in shaping young trees and renovating older specimens deficient in vigour. Winter pruning offers the opportunity of maintaining the desired balance between vegetative activity and fruit production. A healthy established tree with good spur system will require but light winter pruning. When the production of fruiting spurs is excessive a comparatively heavy pruning will serve to supply new vigour which results in increased wood growth.

2. SUMMER PRUNING

The term summer pruning embraces any pruning operations carried out while the plant is in a state of vegetative activity. It is generally practised on young non-bearing trees. Summer pruning consists generally in a reduction of the green parts of the plant by the removal of superfluous and misplaced shoots and by the 'pinching back', i.e. shortening, of laterals which have reached a length of 12 to 16 inches. This, of course, interferes with the processes of plant nutrition and lessens the general vigour. It is owing to this lessening of vigour that summer pruning may be utilised to induce the fruiting habit on trees of strong growth. Unskilful summer pruning may do much harm. To be effective the work must be done at a particular stage; if done too early the check is slight and temporary, and may be followed by buds breaking prematurely into growth. The practice of summer pruning may also assist materially in building up a balanced framework in a young tree, for by pinching out, in the summer, the ends of shoots that are out-growing the remaining shoots a temporary check is administered, and a uniform development of the various shoots obtained.

3. ROOT PRUNING

The term root pruning is applied to two practices diverse so far as results are concerned.

Firstly, there is the practice of severing the roots of established trees. This operation is carried out on trees which are making too much growth and failing to set fruit. The object is of course to bring about a reduction in vigour which will lead to fruiting. The operation is performed by opening a trench round the tree and thereby exposing the main roots which should then be severed cleanly. Upward cuts are better because the growth which pushes from them will have a tendency to strike horizontally rather than downwards. The new growth will therefore develop in the layers of the soil which contain the greatest proportion of plant food, and hence will be suitably placed to supply food when the fruit-bearing habit is assumed. In the case of trees of moderate size the trench may generally be opened at a distance of 3 feet from the stem, and a half-circle of the roots severed the first year, the trench being at once filled in.

Root pruning as described will sometimes cause a shy bearer to fruit by reducing the vigour of an excessively strong grower, but failure to set fruit may also be caused by faulty pollination, and in such cases, of course, root pruning will be of no value in inducing fruit production.

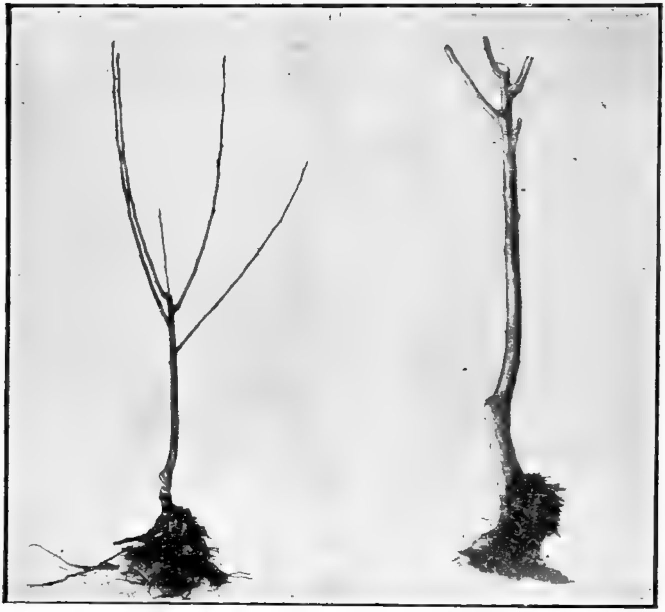


FIG. 136: A two-year-old apple tree showing root and branch pruning. *Left*: Before pruning; *Right*: After pruning

Secondly, root pruning is the term used to indicate the practice of removing, at the time of planting, all injured, torn, or shrivelled portions of the root system. Such portions are not only useless, but are dangerous. They are useless because the root functions are performed by root hairs, which are found on new growth, and to stimulate new growth it is necessary to cut back. Lacerated lengths of roots are dangerous in that decay is prone to become established in damaged tissue and to spread from such tissue to the sound portions.

In pruning the roots at planting it is desirable to cut away any 'toes', i.e., root branches outgrowing the remaining ones, for these, if left on, will maintain their dominance, and a one-sided, ill-balanced root system will be developed.

BUILDING THE TREE

As far as the pruner is concerned, the most important period in the life of a tree is the first few years, during which the framework may be developed and guided in its growth so as to produce the desired type of tree. The type of tree now most generally favoured has a framework varying in shape between an ordinary cup and an inverted cone, set on a sturdy stem ranging in length from 12 to 20 inches.

This type of tree has gained acceptance because:—

(1) It admits of quick, easy, yet safe gathering of the crop.

(2) Pruning and spraying may be easily and effectively carried out.

(3) The supply of light and air which may easily be provided to all parts gives sound prolific growth.

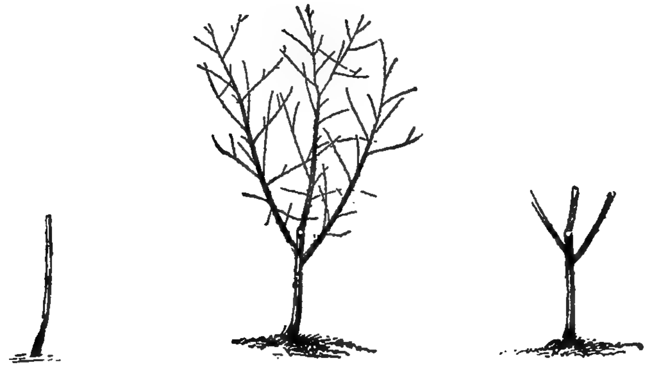
(4) Cultivation can be carried out with reasonable ease.

(5) The effect of winds is minimised.

In brief, the parts of the type of tree referred to are:—

(a) the *trunk* or main stem—12 to 20 inches long, and stout.

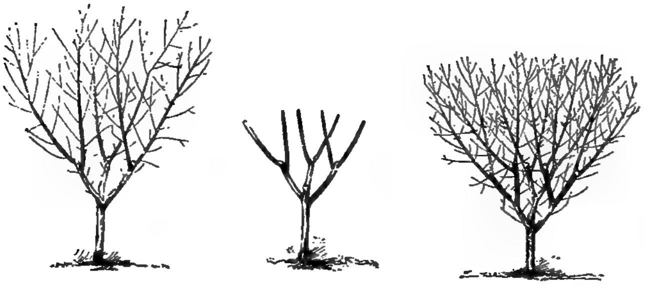
(b) the *main arms,* usually 3 or 4 in number, arising from the trunk in an oblique direction. These should spring from the trunk at, as near as possible, the same level, yet should be sufficiently far apart to possess a separate grip on the trunk so that the stress caused by weight of fruit or by winds, shall not be concentrated on one point. The pruner requires specially to avoid Y-shaped forks, for it is almost certain that sooner or later these will split, with the result that the tree becomes a wreck. The main arms should be as uniform in size as possible, and should be placed at equal distances round the stem so that when viewed from above they form a number of equal-sized angles with arms radiating from one point. The direction of the main arms from the stem varies with the variety, but as a general rule a considerable angle from the vertical is desirable. The length of the main arms varies with their stability, and should be controlled so as to give a permanent framework or scaffolding which will not bend out of proper position when the tree is bearing a full and mature crop. In general, a length of from 6 to 8 inches is adequate. The main arms are generally subdivided into secondary arms, which result from cutting back the main arms to side buds instead of to ones placed on the outside or inside of the limb. The subdividing of the main arms to form secondary arms as far as practicable, should be done at the same level throughout. A main arm usually provides two secondary arms, sometimes three, and occasionally, especially when somewhat stunted, it is left undivided.



Completely headed at planting.

First summer growth.

First winter pruning.



Second summer growth.

Second winter pruning.

Third summer growth.
This should be cut back in the third winter pruning as indicated by small lines.

FIG. 137. Summer growth and winter pruning
(*N.S.W. Dept. of Agriculture*)

(c) *Leaders*—from 8 to 12 or more in number, according to the tree and the climatic conditions. The smaller number is adequate for climates such as those of New Zealand and Tasmania, where the light and heat are less intense than in regions such as South or Western Australia, for which 16 leaders and more in number are recommended by experienced growers. The leaders are formed by subdivision of the secondary arms; they must be strong so as to be able to carry fruit and foliage without breaking, and be able to withstand storms. They should as nearly as possible be equidistant, and should be sufficiently wide apart to allow of adequate access and distribution of light and air. They should not grow towards the centre of the tree; rather they should continue the direction of the secondary arms, being, however, rather more upright. To start the leaders, side or outer placed buds may be used according as the balance of the tree will be best preserved: inner buds, except in trees of a spreading habit, rarely are suitable, as the growth from them, being vertical, has an undesirable advantage, and tends to a crowded rather than to an open framework.

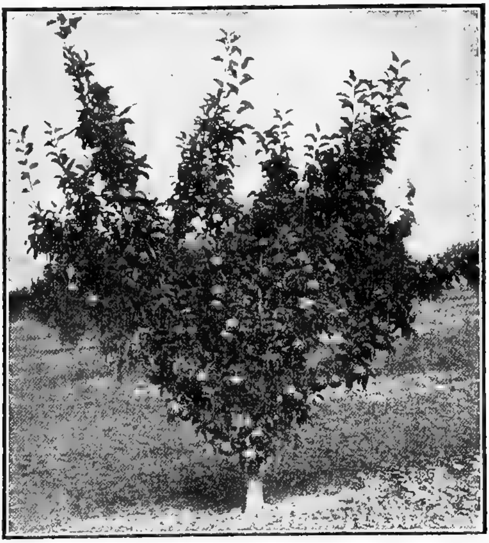


FIG. 138. A well-shaped apple tree. It shows strong framework set on a short stem from which the leaders arise at a suitable angle. The fruits are borne on short spurs ranged close to the strong framework all of which is being used for bearing

(d) *Laterals.*—These comprise the shoots, spurs, and twigs which, though minor in respect of size, are yet of prime importance, for they constitute the bearing portion of the tree. The lateral system varies greatly with the species of plant, and there is even considerable variation within varieties of the same species. Each lateral system demands a definite treatment differing from that required by the others, but in all cases the aim should be to develop in keeping with the vigour of the tree the maximum number of short fruiting laterals evenly distributed over the branches and leaders, and carried as far as possible upon stout parts of the framework.

PRUNING DEVELOPED TREES

The main aim in pruning fruit trees which have developed a sturdy framework, usually after reaching five or six years of age, is to secure a regular and continual replacement of old and unthrifty laterals, spurs and twigs by young healthy ones. This replacement varies according to the type of tree and will be referred to here only broadly and in connexion with pip fruits and stone fruits.

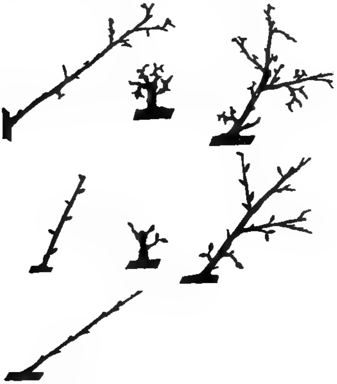


FIG. 139. *Upper*: The type of old, exhausted wood which should be cut back; *Middle*: Healthy fruiting wood; *Lower*: A new lateral, which is the future fruiting wood

(*N.Z. Journal of Agriculture*)

PIP FRUITS

As apple, pear and quince trees fruit on wood two years old or more, winter pruning should aim to promote healthy and vigorous wood of this age in sufficient amount on a tree every year in a four- or five-year cycle. To this end the procedure is as follows:—

(1) New laterals are left uncut for their first year but are thinned to prevent overcrowding. This promotes fruit bud formation early and in good supply.

(2) To prevent overcrowding of current healthy fruiting wood it is shortened where necessary.

(3) Laterals and spurs which are four or five years old and which are becoming unprolific are cut hard back to stimulate new fruiting wood. (See Figs. 139 and 140.)

To rejuvenate old trees which have, through lack of proper pruning, become poor fruit producers, about one-third of the unprolific laterals and spurs are cut hard back at the first winter pruning. During the next three winters the rest of the old laterals and spurs are progressively cut hard back so that ultimately the normal four- or five-year-old cycle of rejuvenation can be followed.

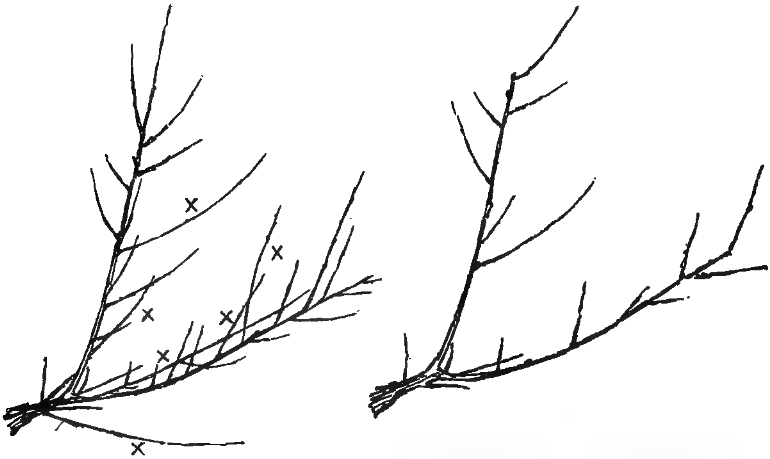


FIG. 140. *Left*: A peach lateral before being pruned, the crosses indicating barren two-year-old wood; *Right*: The same lateral after being pruned (*After N.Z. Journal of Agriculture*)

STONE FRUITS

(a) Because peach and nectarine trees produce fruit only on last year's wood, nearly all the two-year-old laterals are removed every winter and the one-year-old laterals are thinned to avoid overcrowding. This means that more than half the laterals are removed at every winter pruning. Such removal is complete, not to stubs as with pip fruits. Not only is an adequate supply of fruiting wood maintained by this method, but also fruiting wood is being promoted in the lower parts of the tree. Shortening back of the leaders is also necessary for maintaining fruiting wood low down and for inducing new shoots to develop low down also for refurnishing the tree. With most varieties, in order to avoid dieback from the pruned ends of the shoots, the shortening should be to a lateral, preferably to a lateral growing in an outwards direction. (See Fig. 140.)

(b) With plum, cherry and apricot trees fruiting is chiefly on two-year-old laterals and spurs. Hence a three- or four-year cycle for maintaining prolific fruiting wood is required. Every winter one-quarter to one-third of the older laterals and spurs are cut back.

Exercise 1.—(a) Attend a winter pruning demonstration, recording the operations with reasons. (b) Carry out summer pruning on an apple tree or a pear tree, leaving a similar tree untreated as a control. Observe the results during the current season and the following season. (c) In the winter select two pear trees four to eight years old which have not had any special training. Leave one untreated as the control tree. With the other decide upon a strong shoot to be left as the central leader and prune this back slightly. Take three to six other strong shoots evenly spaced around the tree, carefully bend them down to some extent towards the horizontal position and tie them down to stakes driven into the ground at proper intervals around the tree. Continue the bending gradually during the following growing season until the branches are horizontal. During the current season and the following one compare fruit bud development on the branches of the treated tree with that on the control tree.

(d) After the winter pruning of apple trees of the two types, spur bearers and tip bearers, observe flower development in each during the following spring.

(e) Observe the training of apple, pear and other fruit trees on the following systems:—(i) espalier, (ii) cordon.

READING

'The Home Orchard', *Bulletin* No. 310, N.Z. Dept. of Agric.

Fruit Tree and Grape Vine Pruning, Quinn, G.

Pruning of Apples and Pears by the Renewal Method, Thompson.

Deciduous Orchards (Chapt. XV), Chandler.

Fundamentals of Fruit Production, (Sec. 6) Gardner, Bradford and Hooker.

FILMS

(The National Film Library)

'Modern Pruning for Commercial Apple Orchards'

'The Core of the Matter'

'Orange Grower'

26

Weeds

USEFUL farm and garden plants are troubled not only by organisms markedly different from themselves, usually referred to as diseases and pests, but also by organisms much the same as themselves called weeds which are simply highly organised plant pests.

Being usually as highly organised as the plants they damage and being in addition more able to survive under many conditions of intense competition, weeds present great problems in their control and make it likely that we shall never be able to have crops and pastures completely free from them.

The damage caused by weeds to useful plants and animals and their products is great. As weeds cause damage in so many ways, it is difficult to make an accurate estimate of the damage. A British estimate is that weed damage to Britain's crops costs at least £50 million a year.

About the year 1930, Sir Bruce Levy estimated that of the 11 million acres of original forest land in New Zealand sown in pasture about 4 million acres had reverted to secondary growth, that is weeds. Much of this has not yet been recovered. Mr. A. H. Cockayne, a former Director-general of Agriculture, at about the same time estimated that bracken fern, by occupying approximately one million acres of land capable of carrying good pasture for sheep, represents an annual loss in production of over one million pounds money. He also estimated the annual expense of checking twitch weeds on arable land at about £250,000. The lowered annual value of wool due to contamination by burrs of bidibid was reckoned by Dr. D. Miller, Director of Cawthron Institute, to be near £250,000.

Weeds may cause large areas of land to be unfit for farming and may drive farmers off their land. As mentioned earlier in this book in connexion with pasture management and with soil erosion, the abandonment of the whole or portions of farms has occurred in several places in New Zealand. Weed infestation, though only one factor, has contributed in no small measure to such tragedies.

Weeds reduce the carrying capacity of land in pasture and therefore the yield of pastoral products—meat, wool and dairy produce. In addition there are weeds poisonous to stock and there are those which contaminate wool reducing its value. Weeds 'smother' crops, especially those in the seedling stage, and may destroy whole crops. Weeds lower the value of grain. As an English writer puts it, 'Would you like wild radish in your porridge? Probably not, and millers reject many samples of oats because they contain wild radish seeds'. Weeds taint milk and honey.

Circumstances often determine whether or not a certain plant is a weed. In arable country of the South Island, gorse (*Ulex europaeus*) makes a good hedge and in some places provides food for sheep, but on large areas of pastoral land, especially in the North Island, it smothers pasture. Storksbill (*Erodium cicutarium*) with its deep taproot is useful in dry sheep pastures but is a weed in dairy pastures. Prickly pear (*Opuntia*) though usually not a pest in its home continent, America, when introduced into Australia in 1839 soon became a pest. By 1925 it had occupied 60 million acres of land suitable for agriculture.

Many of our troublesome weeds in New Zealand have been introduced from Europe. Notable introductions are gorse, blackberry, ragwort, St. John's wort and thistles. However, several prominent weeds are natives, for example, bracken fern, bidibid, and manuka.

Weeds in a district may be declared noxious weeds in that district. A *noxious weed* is one which by law must be kept under control. Under the Noxious Weeds Act (1950) inspectors of the Department of Agriculture or of a local body advise farmers how to control weeds which have been declared noxious weeds. Farmers must make reasonable attempts to control noxious weeds not only on their paddocks but also on their sides of public roads. Hedges or fences consisting of gorse, hawthorn, boxthorn, seeding barberry, sweet-briar, broom and hakea, must be adequately trimmed every year. There must be no propagation in any way in a district of plants declared noxious weeds in that district.

DAMAGE CAUSED BY WEEDS

Let us consider in more detail the damage caused by weeds.

1. *They deprive the crop of food and air, and particularly of light and moisture.* The harm thus wrought is most striking when the weeds compete with crops of slow development, e.g., mangels, carrots, and lucerne, in their early stages. In a weedy field these

crops in particular are soon 'smothered', and usually the plants never recover properly.

Weeds damage pastures chiefly by their shading effects and by occupying ground capable of growing better plants. Browntop, for example, while valuable in second-class pastures is a weed in first-class pastures.

2. Some weeds act as *hosts for fungi*, and as *nurseries for insects* which cause injury to the crop yield, e.g., aphids and diamond-backed moth are supported by cruciferous weeds such as shepherd's purse and mustard; the leaf miner of cinerarias by sow-thistle. Again, the white rust of cabbages finds a host in shepherd's purse, as also does club-root.

3. Weeds have various *objectionable effects on stock*. Some are more or less poisonous, e.g., hemlock, tutu, ragwort, buttercup, bracken fern. Some penetrate the skins of animals and injure lips, eyes and feet, e.g., barley grass and storksbill.

4. The *value of farm products* is lessened: (a) blackberry, piripiri, Bathurst burr, cause weedy wool; (b) pennyroyal, twin cress, wild mustard, and wild onion cause undesirable taints in milk and its products; (c) the nectar from some weeds, such as ragwort and tutu, taints honey.

5. Some *parasitic weeds*, e.g., broom rape, and dodder (see Chapter 5) may do great damage and even kill a portion of a crop.

6. *Climbing weeds*, e.g., bindweed and wild tares, drag down crops, check their growth, and increase the cost of harvesting.

HOW WEEDS ARE SPREAD

1. An important agent in the distribution of undesirable plants is the *farmer himself*. The use of farm manure before decomposition, and of weed-infested hay and chaff are frequently the cause of weed infestation. Harvesting machinery, when taken from paddock to paddock and from farm to farm without cleaning, is a prominent means of weed seed distribution. But the chief source may be the impurity of commercial seeds. Cockayne gives an instance of white clover seed selling at 1/1 per lb. when good seed could be obtained at 1/6 per lb. The 'cheap' seed contained 230,000 weed seeds to each pound. Again in 1 lb. of a line of timothy of 94.3 per cent purity, he found the following seeds other than timothy:—ragwort, 41,374; Yorkshire fog, 9,513; mouse-ear chickweed, 9,060; *Poa pratensis*, 2,416; docks, 453; sow thistle, 453; Californian thistle, 153. These figures strikingly show the need for the use of pure seed.

2. Weeds are spread by *natural agencies*. Creeks and rivers, especially when in flood, carry many seeds and pieces of plant which act as transplants, e.g., tall fescue, blackberry, willows. A very large number are carried about by the wind. Some of these are provided with flight organs such as wings and fine hairs, e.g., docks, dandelions, thistles, and various grasses. Other seeds are light enough to be readily blown about by the wind, though not provided with appendages. Again, the seeds or fruits of weeds often possess hooks by means of which they become attached to the coats of animals which carry them long distances, e.g. Bathurst burr, piripiri, cleavers, burr clover.

Other seeds again, e.g. sorrel, fathen, blackberry and inkweed, are devoured by animals or birds through which they pass unharmed, and are subsequently deposited long distances from their place of origin.

All these considerations point to the necessity of preventing the weeds reaching the seeding stage. It becomes clear that much harm is annually wrought by weeds being allowed to bloom and mature along roads, railways, and other public areas from which they are readily spread to neighbouring farms.

HABITS OF WEEDS

Many weeds are *annuals*. Germinating in spring they give rise to seeds within the growing season and then die down, e.g., dodder, spurrey, fathen, groundsel, poppy, sow thistle, chickweed, cleavers. These are usually characterised by heavy seed production. For instance, a single sow thistle plant is reported to have produced 19,000 seeds, a plant of fathen has produced 3,123 seeds, and a single monster poppy plant, 480,000 seeds. From these facts we readily understand how annuals quickly overrun a field. Generally, annuals have an extensive surface root system; they make quick growth and produce considerable leafage. Hence they tend to smother slow-growing crops.

Biennial weeds spend their first season's growth in establishing themselves. During this stage their leaves usually lie close to the ground and food is stored in tap-roots, e.g., foxglove, wild carrot, hemlock. In the following season an erect flower-bearing stem is developed, the stored food being used for this purpose.

Many weeds are *perennial*, e.g., ox-eye daisy, couch grass, yarrow, docks. The majority of our most obnoxious weeds are perennials. Many possess a *creeping* habit, i.e., they are examples of the notorious 'twitches'. They often have tough stems which creep on or below the surface of the soil and root freely at the nodes, e.g. sorrel, Californian thistle, yarrow, ragwort, bracken, couch grass (*Agropyron repens*). Each rooted portion of the creeping stem readily becomes a new individual, so that propagation takes place independently of seeds.

Other weeds belong to the *rosette* type. They have very short stems with rosettes of leaves spread on the surface of the ground, e.g., ribgrass or plantain, catsear, dandelion, daisy. Weeds of this type soon crowd out other plants by means of their leaves. Rather difficult to eradicate because of their low habit of growth, many of them are nevertheless susceptible to chemicals, especially hormone weedicides.

CONTROL OF WEEDS

Ever since man gave up a nomadic existence and started to grow crops, weeds have plagued him. The are several Biblical references to weeds. In man's quest for the fruits of the soil, the control of weeds has always taxed his ingenuity. When a farmer sets out to control weeds he must count the cost, for the cost of control must not be greater than the value of the increased production. The cost of weed control depends upon many factors, so it must be very carefully evaluated and such evaluation must be revised from time to time as it may soon become out of date and inaccurate. Thus increased prices for agricultural produce may allow more expenditure on weed control; the production of chemicals on a larger scale makes weedicides cheaper; the discovery of insects or other living agents capable of effective weed control makes for very cheap control.

The use of good cultural practices will always be the main method of weed control. However, a great boost to the use of chemicals as weedkillers has been given since about the year 1940 in the application of mass-produced organic chemicals to the sphere of farm weed control. Biological control, while not so generally spectacular, has nevertheless an assured place in national schemes of weed control.

A. CULTURAL METHODS OF CONTROLLING WEEDS

With pasture occupying a predominant place in New Zealand farming, pasture management must be of outstanding importance in weed control. (See Chapter 18.) Where a high quality, dense sward has been established and maintained there is little opportunity for weeds to exert their strong competitive powers.

However, there is frequently difficulty in establishing high quality pasture unless weeds are cleared away first. There are many loopholes for entry of weeds into well-established pasture. For example the ravages of grass grub and summer drought opens up the pasture and allows thistle seeds to germinate and grow. An unpreventable high water-table in the winter often allows pugging of the soil and development of weeds like buttercup.

The following are important cultural methods of weed control:—

1. Do not allow weeds to ripen seeds. This can be accomplished with surety only by destroying weeds before flowering takes place. Often weeding takes place too late, for frequently the seeds have developed sufficiently to produce new plants while the parent plants are still green.

2. Sow pure seed. (See Chapter 2.)

3. Probably the best method of eradicating weed seeds is to encourage them to germinate by preparing a suitable seed bed. When the seedlings are still small they may easily be destroyed by harrow or cultivator. Weeds, like other living things, are tender and die most easily when they are young. (See Chapter 15.)

4. Fallows and cleaning crops are of great value, because the frequent cultivations given bring countless weeds close to the surface where they germinate and are destroyed by the next harrowing, which operation also brings a fresh lot of seeds near the surface to be destroyed in turn. The underground roots and stems of creeping perennial weeds such as sorrel and couch are also dragged to the surface where they dry out and die.

Potatoes, mangels, swedes and carrots, which require frequent cultivation, are excellent cleaning crops for weed-infested land.

There are drawbacks to the use of fallows and cleaning crops as means of weed eradication, chiefly:—(a) they are of little value in wet seasons, (b) cleaning crops may not fit into the farming system, and (c) the high cost of the labour involved.

5. Repeated cutting at ground level will ultimately destroy even the worst perennial weeds such as Californian thistles and docks, because food reserves in the roots are used up to produce new shoots, and in time the reserves are all exhausted and the whole plant dies. But to succeed in this, the new shoots must be destroyed before they are old enough to build up reserves of food, which means that they must be cut every week or two without fail, throughout the growing season.

Sowing down in lucerne is one way of getting rid of Californian thistle, because the frequent cutting weakens the thistle, and the competition for food, light and water by the vigorously growing lucerne completes the job.

6. Drainage will frequently cause the disappearance of weeds which prove very persistent in ill-drained situations. This is the case with rushes and sedges particularly, and also with loose-strife, pennyroyal, self-heal, watercress and buttercups.

7. The use of fertilisers by promoting vigour in crop or pasture, often enables the desirable plants, which demand high fertility, to compete with success against weeds. Thus, for example, with lucerne stands on potash-deficient soils, the application of potash fertilisers is likely to so stimulate the lucerne plants that weed suppression by the lucerne will at the worst reduce and at the best dispense with the need for chemical spraying to kill grassy weeds.

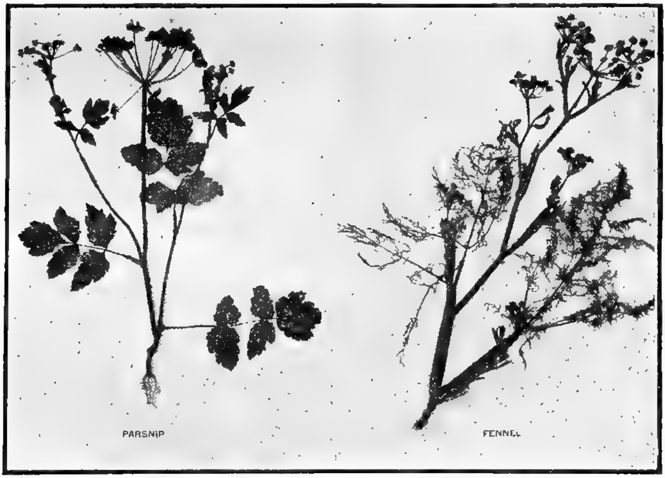


FIG. 141. Two weeds of the carrot family. *Left*: Wild parsnip, an annual or biennial occurring on roadsides and waste places. Prevent seeding, and destroy crowns. *Right*: Fennel, which often forms extensive patches in waste places. Suppress by cultivation or prevention of seeding

8. Grazing management.—On unploughable ground change of class of stock and periodic heavy stocking is the main method of weed control. Thus fern is controlled by heavy summer stocking with cattle just as the fronds uncurl, (see a later section). Sheep will exterminate ox-eye daisy and hold ragwort in check. Bidibid

(*Acaena sanguisorbae*) is controlled by spelling the pasture so that the stolons of bidibid, drawn up with the growing pasture, are not allowed to root at the nodes and are eaten or crushed by grazing cattle.

On ploughable ground used for pasture various cultural methods, followed wholly or in part to control weeds, are employed. (See Chapter 18.)

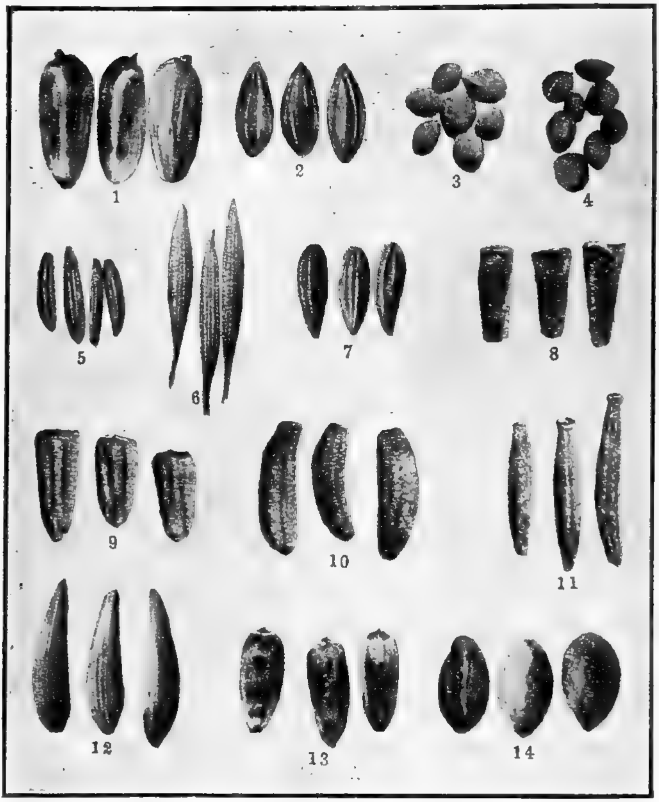


FIG. 142. Weed seeds. 1: Spear-thistle (*Cirsium lanceolatum*); 2: Prickly sow-thistle (*Sonchus asper*); 3: Scarlet Pimpernel (*Anagallis arvensis*); 4: Spurrey (*Spergula arvensis*); 5: Hawkweed (*Crepis capillaris*); 6: Catsear (*Hypochaeris radicata*); 7: Common sow-thistle (*Sonchus oleraceus*); 8: Mayweed (*Matricaria inodora*); 9: Field Chamomile (*Anthemis arvensis*); 10: Ragwort (*Senecio jacobaea*); 11: Groundsel (*Senecio vulgaris*); 12: Nipplewort (*Lapsana communis*); 13: Yarrow (*Achillea millefolium*); 14: Australian flax (*Linum marginale*)

B. Chemical Control of Weeds

'No subject in the whole field of agricultural technology has advanced so rapidly in recent years.'

Just by chance it was discovered in France in the year 1896 that a weak solution of copper sulphate would kill wild turnip growing in cereal crops without doing much harm to the cereal. Later dilute sulphuric acid was found effective. Sodium chlorate and

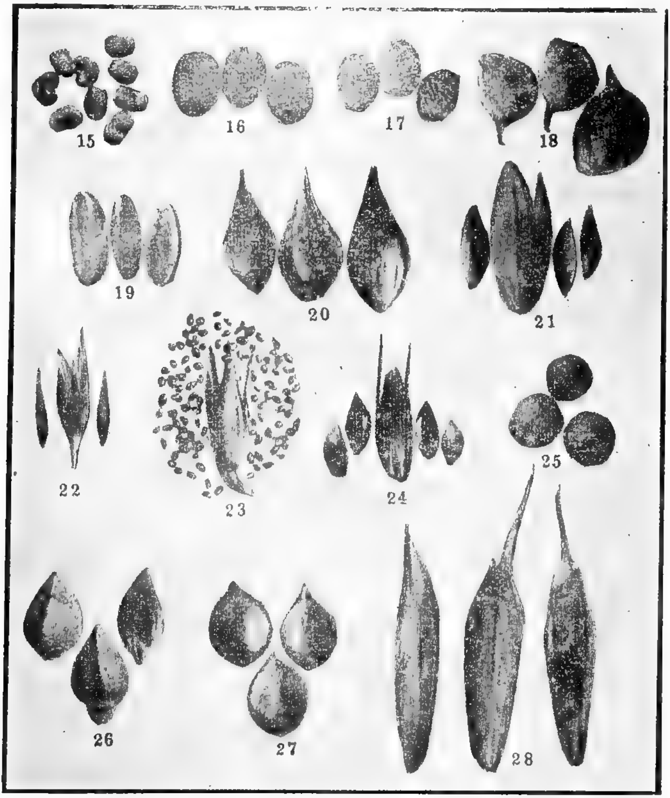


Fig. 143. Weed seeds (continued) 15: Catchfly (*Silene gallica*); 16: Cut-leaved Cranesbill (*Geranium dissectum*); 17: Soft Cranesbill (*Geranium molle*); 18: Creeping buttercup (*Ranunculus repens*); 19: Ribgrass (*Plantago lanceolata*); 20: Sedges (*Carex* sp.); 21: Yorkshire Fog (*Holcus lanatus*); 22: European Hair-grass (*Aira praecox*); 23: Toadrush (*Juncus bufonius*); 24: Sweet Vernal (*Anthoxanthum odoratum*); 25: Wild turnip (*Brassica campestris*); 26: Wireweed (*Polygonum aviculare*); 27: Redshank (*Polygonum persicaria*); 28: Goosegrass (*Bromus mollis*)

arsenical compounds were useful where drastic treatment against weeds was needed. Then in the 1930s a revolution in chemical industry saw the development of organic chemicals from small scale in the laboratory to large scale in the factory. Testing of many of these synthetic organic compounds as weedicides (and as fungicides and insecticides too, see Chapters 23 and 24) soon followed. As Sir John Russell puts it, 'Organic substances have the great advantage over the simple inorganic substances (such as those mentioned above) in that they can be built up into families of similar pattern. Each member is distinct and differs from the others only in the number and arrangement of the atoms, or groups of atoms, of which it is composed. Some graduation of many of their properties can be made by systematically adding to or removing particular groups of atoms'. Glimpses of this situation can be seen from a study of the full chemical names of the various organic fungicides, insecticides and weedicides.

With the discovery of *2,4-D* (2,4-dichlorophenoacetic acid) and related phenoxyacetic acid compounds with their selective weed killing properties, the solutions to many serious weed problems have been found. Other organic chemicals such as *TCA* (Trichloracetic acid), phenols, carbamates such as *C.I.P.C.* (isopropyl-N- (3 chlorophenyl) carbamate), and urea compounds such as *Monuron* (3-(3,4-dichlorophenyl)-1, 1-methylurea) have their special places in weed killing programmes.

All these organic compounds are *selective weedicides,* i.e. they affect some plants more than others, or can get into them more easily. They allow the selection of a particular weedicide for a particular crop. A universal weedicide to kill all weeds and spare all crops is never likely to eventuate.

The use of chemical weedkillers or weedicides (also called herbicides) demands high standards of farm management. A farmer, while not having the time to acquire much knowledge of the chemical and biological properties of weedicides, will nevertheless have to know something about them so that he will know when he is well served by chemical weed control specialists.

Chemical weedkillers are a very useful weapon in the war against weeds, although they can never take the place of good husbandry. The cost of material and the difficulty of large-scale application often limit the extent to which they can be used. In special cases the aeroplane and the helicopter have proved useful.

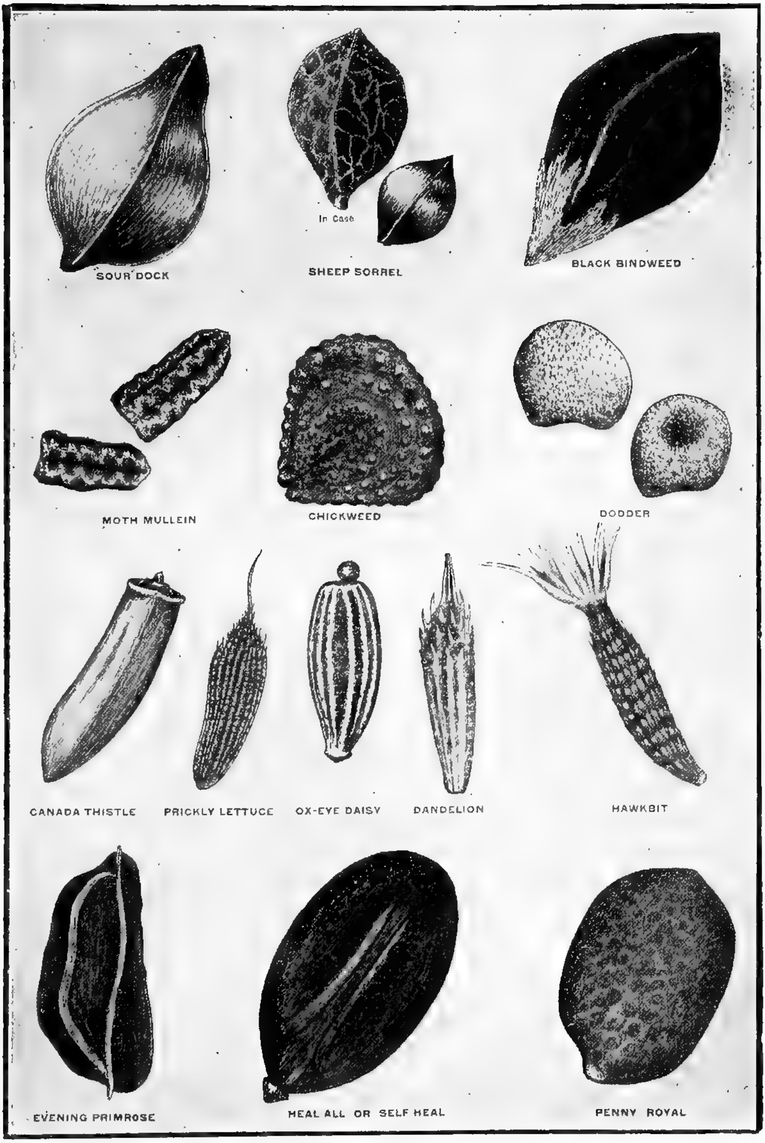


FIG. 144. Seeds of common weeds

Weedicides can be divided into two main groups.

(1) Contact weedicides which destroy only those parts of the plant with which they come in contact.

(2) Translocated weedicides which can be translocated in the sap stream throughout the whole plant.

(1) CONTACT WEEDICIDES

Sulphuric acid, sodium chlorate, arsenic, and the salts of dinitro-ortho-cresol are effective against annual weeds, and against seedling plants of biennials and perennials, but they cannot destroy well established perennials, because they cannot penetrate the roots.

Sodium chlorate has sometimes completely destroyed Californian thistle, but success in this depends on sufficient rain falling to wash it down into contact with the roots soon after it is applied.

T.C.A. (Trichloracetic acid) is usually produced for weed killing as the sodium salt of trichloracetic acid at 90 per cent strength with an acid equivalent of 79.3 per cent. A good grass killer when in contact with the roots, T.C.A. is best applied to cultivated ground. The twitch grasses are the most susceptible of the perennial grasses to T.C.A. Used as a *pre-emergent spray*, i.e. sprayed on the ground after sowing a crop and before emergence of the seedlings, it kills also the seedlings of many broad-leaved weeds such as red shank and fathen. T.C.A. should be kept in watertight bags during storage to prevent absorption of water from the atmosphere resulting in loss of weedicidal value.

C.I.P.C. (Isopropyl-N-(3 chlorophenyl) carbamate). Like T.C.A., C.I.P.C. is a good grass killer but, under rather dry conditions, it is more effective than T.C.A. Nevertheless to be effective it needs moist soil. Acting best with pre-emergent application, C.I.P.C. will kill, besides grass seedlings, a large variety of broad-leaved weed seedlings such as chickweed and docks.

(2) TRANSLOCATED WEEDICIDES

Carried by the sap, translocated weedicides stream down throughout the whole root system, and can thus destroy the plant completely with no possibility of recovery. The 'hormone' weedkillers are the chief ones in this group, and their extraordinary ability to penetrate the whole plant is due to the fact that they are closely related to the natural growth hormones that control the growth of all plants. In minute quantities they stimulate growth just as the natural hormones do, but in larger quantities they completely disorganise cell production and growth, and the plant dies.

For best results against deep-rooted perennials, sprays usually should be applied when the plant is sending down surplus foodstuffs for storage, because the hormones are carried down with them deep into the roots. This occurs when the plant has finished its upward growth and is starting to flower. The plant needs very little food for flowering and seed-setting and, as it is no longer growing but is still manufacturing food, most of this is 'surplus' and is sent down for storage.

CLASSIFICATION OF HORMONE WEEDICIDES

Three acids constitute the parents of most of the hormone weedicides commonly used at present in New Zealand.

They are:—

2,4-D (2,4-dichlorophenoxyacetic acid)
2,4,5-T (2,4,5-trichlorophenoxyacetic acid)
and *M.C.P.* (2 methyl, 4 chlorophenoxyacetic acid)

From each of these three acids three kinds of compounds useful as weedicides are produced, namely, salts, amines and esters. A *salt* is the product of the neutralisation of an acid by a base. An *amine* is a derivative of ammonia, NH_3, obtained by replacing one or more of the hydrogen atoms by organic radicals. An *ester* is the product of the union of an organic acid with an alcohol. The usual kind of salt is the sodium salt of the parent acid, but sometimes the potassium salt is used. In *hormonised superphosphate* it is the sodium salt of 2,4-D which is mixed with the superphosphate. By using such a mixture the cost of application of weedkiller is nil.

Generally speaking salts and amines of 2,4-D are used effectively against broad-leaved succulent weeds. Salts and amines of M.C.P. are also used against such weeds and are safer with certain crops than 2,4-D because they cause little injury to crops but, being more expensive than 2,4-D, less acreage is treated.

Salts and amines are soluble in water but most esters are oil soluble. Provided succulent plants are growing well when treated with the weedicides, salts and amines are in general better killers than esters. If the reverse situation holds or the plant is at the seed-head stage of growth or the plants are woody, then esters are better. This is apparently because esters penetrate better. Esters, being oil based, are less readily washed off the weeds to which they have been applied than are salts and amines. Hence esters are better if rain falls soon after application.

COMPARING ORGANIC WEEDICIDES

In order to compare the concentrations of weedicides and to follow a recommended treatment it is necessary to know the *acid equivalent of a weedicide*, i.e. the amount of parent acid in the weedicide preparation in pounds per gallon. Recommendations are given as pounds of acid equivalent an acre.

PROCEDURE IN APPLYING HORMONE WEEDICIDES

(1) Choose the best form of weedicide according to the type of weed and its stage of growth. With annuals and seedling perennials the younger the growth the more easily is the weed killed. With established biennials and perennials susceptibility is greatest at the stage of greatest leaf production, usually when the flower stalk is just beginning to shoot, or, in the case of woody plants, when flower buds have just formed.

(2) There should be as much covering of the leaves with spray as possible. As the rate of dilution is unimportant, the spray should be made with the recommended quantity of acid equivalent an acre in enough water to allow maximum coverage without much run-off.

(3) With certain crops such as maize, potatoes and bulbs, hormone weedicides may be applied before sowing the crop, *pre-sowing application*, or as pre-emergence application. By these methods weeds are killed at their most susceptible stage, the germination stage, and many weeds which are resistant to post-emergence applications are dealt with.

VALUE OF HORMONE WEEDICIDES

(a) *Advantages*:—(1) Being non-poisonous to animals they can usually be used where livestock have access to treated plants. Where, however, poisonous plants such as hemlock have been treated, livestock should be kept off the treated area for three or four days. The hormones make the plants more attractive to livestock without reducing their poisonous properties.

(2) Because they are non-corrosive they are easily handled and do not require special apparatus.

(3) When properly used they are highly selective being generally highly toxic to broad-leaved plants but have little adverse effect upon cereals and grasses. Hence most broad-leaved weeds in cereals can be killed without seriously affecting the cereals. (See Chapter 19.)

(4) Largely due to their movement in plants they are very efficient.

(5) Having done their work they disappear, being decomposed by soil organisms.

(b) *Disadvantages*:—(1) Being hormones they affect the living processes of *all* plants, crops and weeds. Hence, by spray drift, damage will be caused to susceptible plants nearby. Spraying is less troublesome than dusting in this connection. Spraying should be done in calm weather, often best in the early morning. Too fine a spray should be avoided by using a large amount of water, coarse nozzles, and low pressures.

(2) The selectiveness of hormone weedicides while often an advantage can also be a disadvantage. Some weeds, such as grass weeds, which they do not kill, grow better after their application than before because some of their weed competitors are destroyed.

(3) In contrast to the contact weedicides the hormone weedicides kill weeds only slowly, a matter of weeks or months instead of hours or days. This defect is very apparent with treated lawns. It means that lawns should not be mown for at least a week after treatment to allow sufficient time for the hormone to be transported to the roots and so kill the weeds.

(4) When applied to pasture, hormone weedicides often cause grave damage to the clover. However by replacing the acetic acid group in the molecule of M.C.P. by a butyric acid group a compound called *M.C.P.B.* has been produced free from this limitation. A similar replacement with 2,4-D has produced 2,4-D-B. Both M.C.P.B. and 2,4-D-B are useful not only on pastures containing clover but also as a weedicide for leguminous crops such as peas.

Dalapon (2,2-dichoropropionic acid) though not a hormone weedicide acts like them in moving in plant sap, but unlike them is a good grass killer. It is sold as the sodium salt. Whereas

T.C.A., another good grass killer, acts mainly throught the roots, Dalapon acts mainly through the shoots. Like T.C.A., Dalapon decomposes in water and loses its weedicidal value, so it should be stored in watertight bags. Being a translocated weedicide, it is applied in a way similar to that for hormone weedicides.

At 1 to 2 lb. per acre applied in the spring to barley grass (*Hordeum murinum*) just before early flower head formation, Dalapon will kill the barley grass without severely injuring valuable grasses.

WEEDICIDES AS SOIL STERILISERS

Where death of all vegetation on an area is required, as on vacant plots, restricted areas in a crop, footpaths and railway tracks, one of several non-selective weedicides, or a mixture of two of them, is used. Which one is chosen depends upon several factors, chiefly:—(a) the length of time the soil is to be rendered sterile, (b) the ease of handling and application, (c) the cost.

(a) *Sodium chlorate* kills both by contact with the foliage and through absorption by the roots. Its effectiveness may last about six months. A grave defect of sodium chlorate is its high inflammability.

(b) *Boron compounds,* such as Borascu which is a mixture of boron trioxide and sodium borate, may give complete weed control for a year or more. Acting only when absorbed by roots, boron compounds should be applied in wet weather.

(c) *Monuron* (3-(3,4-dichlorophenyl)-1, 1-methylurea). One of several urea compounds used as weedicides, Monuron is, like all of them, safe to handle and easy to apply, and acts through absorption by roots. At low rate of application Monuron is a useful pre-emergent weedicide. At high rates the soil may be rendered sterile for several years and it is then that it is useful where plant life is not wanted. In spite of its high cost its use may be justified where, as on footpaths, its long term residual effects make fewer applications necessary compared with cheaper weedicides with shorter residual action.

C. BIOLOGICAL CONTROL OF WEEDS

It was about the year 1902 during the search for natural enemies of insect pests that the biological control of weeds started. The shrub, *Lantana camera*, had become a serious weed in Hawaii and it was noticed that a scale insect, accidentally introduced into Hawaii, had attacked *Lantana* severely. This led scientists to seek other insects attacking *Lantana*. They went to the home of *Lantana*, namely Mexico, where several insects attacking the plant were discovered. These were sent to Hawaii where they secured a great reduction in the prevalence of the weed.

Probably the greatest achievement in the biological control of weeds was the almost complete destruction of Prickly Pear (Opuntia) in Australia by the caterpillar of a moth, *Cactoblastis cactorum*, imported in 1925 from Argentina, one of the homes of Prickly Pear. By 1933 most of the Prickly Pear on 60 million acres, about half this area covered with dense pear, had been destroyed. By 1940, 22 million acres of land formerly covered with dense pear had been brought into agricultural production.

Work on the biological control of a weed is always slow. In addition to the large amount of selecting, testing, freeing from parasites, breeding, and liberating of the attacking insects, great care must be taken to ensure that the chances of an introduced insect attacking useful plants is negligible.

In New Zealand there has been much work on the biological control of weeds, chiefly with blackberry, bidibid, ragwort and gorse. Blackberry, being closely related to apple, rose and other useful plants proved a difficult subject. No suitable insect which would not attack related useful plants cound be found.

A Chilean sawfly showed prospects of considerably reducing burr formation on bidibid. However, after passing rigorous tests, it was found unable to establish itself outside the laboratory. Ragwort, being unrelated to useful plants, did not need rigorous testing. One of the insects tested and partly established in the field, the Cinnibar Moth, chosen for its caterpillars with voracious appetites for Ragwort, has barely survived. Birds like the caterpillars. Another insect has been more successful. It is the Ragwort Seed-fly, the maggots of which live in the flower and destroy the seed.

In controlling gorse, a valuable plant in some places, the aim has been only to check the seeding of the plant. A European seed-weevil was selected, tested and successfully established in the Auckland Province. The female weevil lays its eggs in the green pod; the grubs eat the seeds, pupate and develop into young adults. When the pods are ripe, young weevils instead of ripe seeds are shot out.

SOME IMPORTANT WEEDS AND THEIR CONTROL

Bracken Fern (*Pteridium aquilinum*, variety *esculentum*)

One of the worst weeds of unploughable country throughout New Zealand, bracken fern is a difficult weed to control. Like all pests, a knowledge of its structure, habit of growth and life history is essential for adequate control measures to be devised.

Its much-branched, stout rhizomes, rich in stored food, maintain and replenish the aerial parts. Before Europeans came to New Zealand, the Maoris tended bracken fern for its rhizomes which they dug up and ground up. They separated the white floury portion from the black fibres, and used the flour for food.

The conspicuous fronds measure 2 ft. to 12 ft. in length when mature. As the fronds emerge from the soil, they are curled, the delicate growing point being protected inside the curl. In the summer, spore cases develop in a continuous band on the under surface of a leaf at the margin.

Ferns are less highly organised plants than Angiosperms and Gymnosperms. This is shown especially in their mode of reproduction. As with even simpler plants, the fungi and the bacteria, single-celled structures called spores are produced for reproduction as contrasted with the many-celled seeds of Angiosperms and Gymnosperms. In sexual reproduction the male gamete of ferns is poorly protected compared with the male gametes of the higher plants. Instead of being enclosed in a pollen grain, the fern male gamete or sperm is exposed, and, in order to keep alive, must be immersed in water. It swims to the female gamete or egg to effect fertilisation.

The Life Cycle of a Fern

There are really two kinds of plant produced in the life cycle of a fern, the spore-producing plant which is the commonly recognised fern plant, and the gamete-producing plant which is small and inconspicuous. The life cycle of bracken fern, (refer also to the diagram) is as follows:—From the large, spore-producing bracken fern, the *sporophyte*, ripe spores are released in the summer and are blown about by the wind. A spore landing on a moist, shady place germinates and grows into a tiny plant called the *prothallus* which is pale green, thin and heart-shaped, and about one-quarter inch long when full grown. Strands called *rhizoids* attach the plant to the soil and absorb water and salts. Because the prothallus when mature produces gametes, male and female sex cells, it is also called the *gametophyte*.

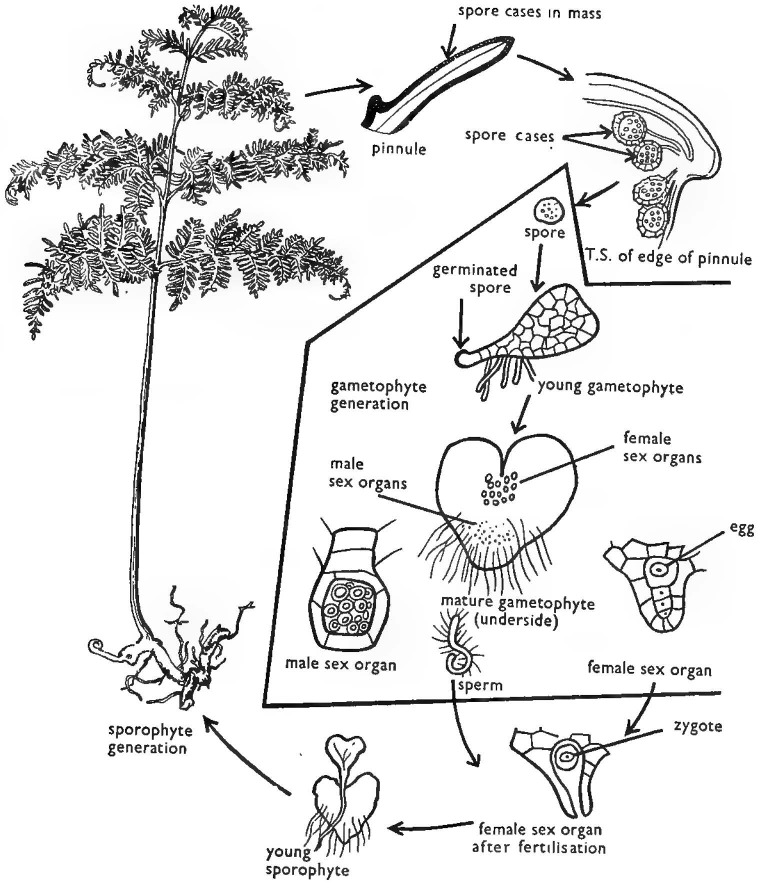


FIG. 145. Life cycle of bracken fern

On the under side of the gametophyte among the rhizoids there are male organs, more or less spherical in shape, which produce the male gametes or sperms. Also underneath but near the notch there are the female sex organs, flask-shaped, each producing an egg at its base. When the gametophyte is wet with rain or dew, sperms from ripe male sex-organs swim towards the ripe female sex-organs. Entering the canal of the female organ, the sperms swim towards the egg, one sperm only uniting with the egg and fertilising it, making a zygote, the beginning of a new sporophyte generation. By division of the zygote the young sporophyte develops while still attached to the gametophyte and drawing nourishment from it. Only one sporophyte develops from each gametophyte. With the withering of the gametophyte and the rooting of the sporophyte a new sporophyte generation now leads an independent existence. When mature, the new sporophyte produces spores and a new cycle starts. There are thus with ferns two kinds of plants, the conspicuous, spore-producing plant and the inconspicuous gamete-producing plant, alternating with each other in a life cycle. Ferns are therefore said to show *alternation of generations.*

CONTROL OF BRACKEN FERN

On ploughable country the control of bracken fern presents no problem. It is on unploughable country that the control is difficult. On the principle of attacking a pest at the weakest stage in its life history, bracken fern on unploughable country is burnt in the late summer when its fronds are driest. Soon afterwards pasture seeds are sown with fertiliser in the ashes of the burn. In the spring when the fronds, not beyond the curl stage, have developed from food stored in the rhizomes, the area is grazed with cattle at high concentration. If the pasture has grown well so that the cattle can be kept on the area without starving them, the curled fern fronds are continually eaten off with the pasture or broken off by the hooves. Thus the food supply in the rhizomes is used up and the fern dies. If pasture is scarce, the cattle are likely to suffer from fern poisoning shown by 'lack of thrift, dullness, emaciation, loss of appetite, and discharge of blood from the rectum with the faeces'. At the first signs of such symptoms the cattle should be removed to better pasture to recover and replaced by a fresh mob to prevent the fern growing beyond the curl stage when it is left ungrazed and too tough to be crushed. If the fern gets out of control in patches, these patches should be burnt, resown and grazed as before.

OBSERVATIONS OF BRACKEN FERN

Exercise 1.—(a) Collect a specimen of bracken fern consisting of frond, rhizome and roots. Make a sketch of it.

(b) Cut a piece of rhizome crosswise and lengthwise and examine the sections under a magnifying glass. Sketch what you see.

(c) Cut a pinnule across. Examine the T.S., near the edge of the pinnule, under a magnifying glass and also under a microscope. Sketch what you see.

(d) Try to find prothalli on moist banks in the bush or in a fernery. Look, with the help of a magnifying glass, at the underside of a prothallus for male and female organs and rhizoids.

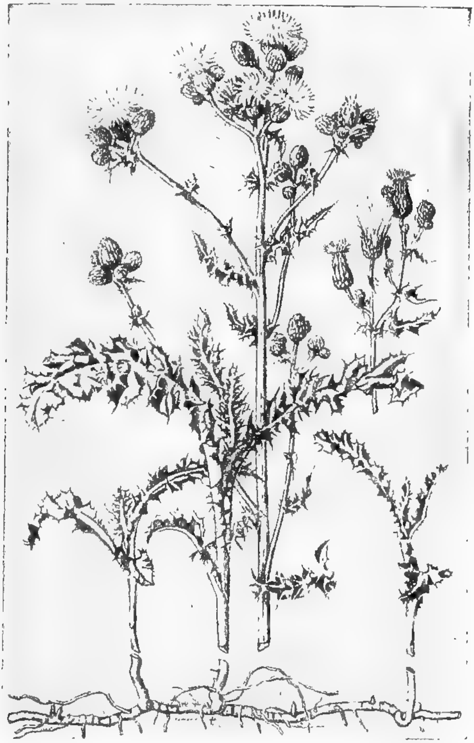


FIG. 146. Male plant and creeping stems of Californian thistle. At side, on right, female heads

CALIFORNIAN THISTLE (*Cirsium arvense*) also called Creeping and Canadian thistle, is a serious perennial weed propagated both by seeds and by deep and extensive rhizomes. Pieces of rhizomes left in the soil grow so that ordinary cultivation only spreads the pest. Eradication consists in either destroying the rhizomes by regular hoeing and so keeping them deprived of green leaves, or by applying hormone weedicide at the most susceptible stage of growth. In arable land cultivation in preparation for a crop or for pasture will stimulate dormant roots and rhizomes into active life.

If a crop, such as wheat, oats, barley, maize, potatoes and pasture, resistant to hormone weedicides, is then grown so that the crop is not at a susceptible stage of growth but the thistle is—that is, at the maximum leaf stage about 4 to 6 months after the last cultivation—then the thistle is usually killed by one application of M.C.P. at 1 lb. an acre.

On established pasture repeated cutting from early spring to late summer will cause some loss of food from the rhizomes and produce young, active growth. Then in the autumn the thistle at the rosette stage is sprayed with M.C.P. at 1 lb. per acre. Spraying may have to be repeated twice more annually.

OBSERVATIONS OF WEEDS

Exercise 2.—(a) Collect, press and mount specimens of weeds, and record the habitats from which the specimens were obtained.

(b) In the autumn observe about weeds:—
  (i) Those which are drought resistant and
  (ii) the root development of weeds.

(c) In the winter note:—
  (i) weeds which are killed by frost,
  (ii) those which survive frost,
  (iii) those which grow in the winter.

(d) In the spring as weeds come into flower make a list of them, classify them early, medium and late, and also according to their flower colour.

(e) As you observe weeds during the year classify them according to habit of growth along such lines as:—upright, procumbent, creeping without rooting, creeping and rooting at the nodes, rhizomatous, rosette, tap-rooted, climbing.

(f) Classify weeds according to flower structure into families, chiefly:—grass, pea, turnip, dock, rose, carrot, snapdragon, mint, and daisy families.

(g) Make a list of weeds in such places as:— (i) continually grazed pasture, (ii) pasture often cut for hay or silage, (iii) places usually not grazed and not cultivated, (iv) arable land, (v) lawn, (vi) vegetable garden, (vii) hedge.

(h) Observe the colonisation of ground by plants under one or more of conditions such as the following:—(i) newly sown plot or paddock, (ii) newly drained area, (iii) shingle slip, (iv) slip on the roadside, (v) new filling as on a roadside, (vi) flood deposit.

OBSERVATIONS OF WEEDICIDES

Exercise 3.—(a) Try the effect of spraying gorse at various stages of growth and at various times of the year with 2,4,5-T at recommended strengths.

(b) Compare the effects on established pasture of 2,4-D and 2,4-D-B sprayed on at recommended strengths.

(c) Before sowing or just after sowing a crop or pasture apply sprays of two or more of the following and compare the effects:—T.C.A., C.I.P.C., 2,4-D, M.C.P., Dalapon, Monuron, all at recommended strengths.

READING

Weeds of New Zealand, Hilgendorf, F. W., and Calder, J. W.
Science News, 31, (p. 103), Higinbotham, R. N.
New Biology, 8, (p. 51), Wilson, F.
Agriculture, Apr. 1958, (p. 5), Russell, Sir E. John
N.Z. Dept. Agric. Bulletins, Nos. 329, 202
N.Z. Grasslands Assoc., *Proceedings*
Service, Vol. 2, No. 2
Massey Agric. College Sheepfarming Annuals
N.Z. Fertilizer Journal
N.Z. Journal of Agric., 'Weed Identification and Control', 1958; 'Poisonous Plants', 1951
Canterbury Chamber of Commerce Agric. Bulls. Nos. 278, 289, 348
N.Z. Journal of Agricultural Research

Appendix

PREPARATIONS OF SOLUTIONS

1. Ammonium Molybdate Solution

Add 70 gm. of ammonium molybdate to 100 cc. of water in a flask. Then add 100 cc. of strong ammonia, cork the flask, and shake until the ammonium molybdate crystals are dissolved. Pour the solution into 720 cc. of cold nitric acid (specific gravity about 1.20), stirring whilst adding. Allow to stand overnight; then pour off the liquid from the residue which has settled.

2. Fehling's Solution

This is best made as two solutions, No. 1 and No. 2. No. 1 contains 35 gm. of copper sulphate dissolved in 500 cc. of water. No. 2 contains 173 gm. of Rochelle salt (sodium potassium tartrate), and 160 gm. of potassium hydroxide dissolved in 500 cc. of water.

3. Indigo Solution

Place 4 gm. of indigo (solid) in 50 cc. of concentrated sulphuric acid (pure). Allow it to stand for 24 hours. Then make up to 1 litre by adding distilled water and filter.

4. Iodine Solution

Dissolve 1 part iodine (crystals) and 2 parts potassium iodide in 50 parts (by weight) of water.

5. Limewater

Slowly slake fresh quicklime by adding water to the lumps so that they fall to a powder. Slowly add more water so that a paste and then a cream-like consistency is obtained. Increase the bulk several times by adding more water, allow it to stand for a short while and then filter, obtaining a clear liquid which must be kept air-tight.

6. SODIUM OR POTASSIUM PYROGALLATE

Dissolve 1 part (by weight) of pyrogallic acid in 15 parts of water, and 5 parts of caustic potash (or caustic soda) in 15 parts of water (by weight). Mix the two solutions immediately before the pyrogallate is to be used.

7. DIPHENYLAMINE SOLUTION

To 10 gm. of diphenylamine powder add 22 ml. of absolute alcohol. Keep in darkness. It gives a deep blue colour with a solution of a nitrate acidified with sulphuric acid.

8. SODIUM COBALTINITRITE SOLUTION

Dissolve 250 gm. of sodium nitrite in 500 ml. of distilled water. Add 150 ml. of 6N. acetic acid and 25 gm. of cobalt nitrate crystals and let the mixture stand overnight. Filter or decant the solution and dilute to 1 litre.

9. PICRIC ACID SOLUTION

Dissolve 10 gm. of sodium carbonate powder in 200 ml. of distilled water. To the solution add 1 gm. of picric acid and shake. Cut strips of filter paper two and a half inches by three-eighths of an inch, soak and drain.

10. STARCH SOLUTION

Make 2 gm. of solid starch into a paste with cold water. Add 100 ml. of cold water and boil for 5 minutes. Allow to stand and pour off the clear liquid.

11. STANDARD ACIDS AND ALKALIS, approx. 2N.

(a) *Hydrochloric Acid*:—One part by volume of concentrated acid to four parts of water.

(b) *Nitric Acid*:—One part of conc. acid to 10 parts of water.

(c) *Sulphuric Acid*:—One part of conc. acid to 20 parts of water.

(d) *Sodium hydroxide*:—80 gm. in water and make up to one litre.

(e) *Ammonium hydroxide*:—One part by volume of 0.88 ammonia to three and a half parts of water.

12. INDICATOR SOLUTIONS

(a) *Litmus*:—Warm 10 gm. of solid litmus with 250 ml. of water for six hours without boiling. Decant the clear liquid and turn purple by adding two drops of methyl acetate.

(b) *Phenolphthalein*:—Dissolve 1 gm. of the solid in rectified spirit and dilute to 1 litre with a mixture of water and rectified spirit 1 : 1.

(c) *Methyl Orange*:—Dissolve 1 gm. of the solid in rectified spirit and dilute to 1 litre with a mixture of water and rectified spirit 1 : 1.

13. STERILE AGAR

To nutrient agar for bacteria add cold, freshly distilled water at the rate of 23 gm. of agar to 1000 ml. of water. To potato dextrose agar for fungi add cold, freshly distilled water at the rate of 39 gm. of agar to 1000 ml. of water. In either case shake up in a flask and heat to boiling point to dissolve the agar completely. After pouring 15 ml. of the liquid agar into each of several test-tubes, stopper them with flamed cotton-wool. Sterilise the test-tubes and contents in a pressure-cooker for 15 minutes at a pressure of 15 lb. per square inch.

14. METHYLENE BLUE STAIN FOR BACTERIA

Dissolve 0.3 gm. of methylene blue in 30 ml. of ethyl-alcohol and mix with 100 ml. of distilled water.

15. STAINED LACTOPHENOL FOR FUNGUS MOUNTS

Dissolve 100 gm. of phenol in 100 ml. of lactic acid, 100 ml. of glycerine and 100 ml. of distilled water. Add any bacterial stain such as erythrosine, 3 ml.

PRESERVING PLANT MATERIAL

(a) *Dry Specimens*:—Press lightly between newspaper on a flat surface for one or two days and then change the paper and press heavily for two or three days. With juicy specimens a third pressing after change of paper is necessary for a few more days. Mount on paper or cardboard attaching with cellotape and recording date, name and habitat.

(b) *Wet specimens*:—Clean the specimens by washing in water and place in screw-top jars with the following preservative:—Ethyl alcohol 95 per cent, 1 litre; formaldehyde 40 per cent, 100 ml.; glacial acetic acid, 100 ml.; water, 1 litre; saturated copper sulphate solution, 50 ml.

STERILISING GLASSWARE FOR USE IN MICROBIOLOGY

After washing the glass vessels in hot soapy water, rinse them in clean cold water and then sterilise them by immersing in boiling water for 20 minutes.

Index

ACIDITY in soils, 173-80
  cation exchange, 174
  correction of, 177-9
  effect of liming on, 222
  effect on trace elements, 218
  hydrogen ions, 173
  increasing, 179
  measurement of, 175
  pH, 175
Acids and alkalis, standard solutions, 495
Adventitious buds, 35; roots, 42
Aeration of soil, 159, 241
Aerobic organisms, 184
Agar, 496
Alfalfa, 348
Alkalis and acids, standard solutions of, 495
Alluvial soils, 136-9
Alsike clover, 275
Aluminium, 39
Ammonium molybdate solution, 494
Ammophos, 211
Anaerobic organisms, 184
Analysis of plants, 40, 169
Analysis of soil, 170
Androecium, 97, 99
Angiosperms, 8
Annual rings, 28
Annual weeds, 474
Anthers, 97
Aphids, 441
Artichoke, Jerusalem, 357
Auricles, 261
Auxins, *see* hormones, 92
Azonal soils, 136

BACTERIA, 183-94
  aerobic and anaerobic, 184
  denitrifying, 186
  fixation of free N., 186
  influence of pastures on, 189
  nitrifying, 185
  symbiotic bacteria on legumes, 187
  types of, 184
Bactericides, 430
Bark, 26-7
Barley, 330
Basic slag, 204
Basic superphosphate, 198, 203
Bast, 27, 82
Beets, 354
Biennial weeds, 474
Biological control of insects, 454
  of weeds, 486
Black-spot of apples, 412
Blight of potatoes, 407-9
Blood and bone, 212
Blue tussock, 272
Blue wheat grass, 272
Bonedust, 212
Bordeaux mixture, 427
Boron, 39, 197, 221
Bracken fern, life cycle of, 488
  control of, 490
Bract, 80
Breeding of plants, 113-20
Broom rape, 77
Brown-grey earths, 134
Brown-heart of swedes, 424
Browntop, 268
Budding, 394-6
Buds, 34-8
  structure of, 35
  types of, 34
  wood and fruit, 37, 261
Bulbs, 33
Bushel weight, 21

CALCIUM, uptake of, 52
  deficiency of, 173
  see also Lime
Calcium cyanamide, 210
Californian thistle, 491
Callus, 29
Calyx, 96
Cambium, 24, 26, 27
Carbohydrates, 9, 64
  composition of, 9-10
  manufacture of, 64-72
Carbon, 52
  fixation in plants, 64-72

Carbon dioxide, 64-72
  in photosynthesis, 69
Carpels, 97
Carrot, 354
Caryopsis, 261
Catalysts, 39
Cation exchange, 174, 222
Cells in plants, structure of, 23
  division of, 24
Cellulose, 23
Certification of seeds, 276-82
  picric acid test, 282
  standards of, 280
  U.V. tests, 281
Chewings fescue, 271
Chlorine, 39
Chlorophyll, 23, 65, 69, 76
Chloroplasts, *see* Chlorophyll
Chou moellier, 339
Cladodes, 32
Clay, 142-4
  colloidal, 143
  flocculation of, 144
  permeability of, 160
  see also Soil Classification, 146-9
Clubroot, 409
Clovers, identification of, 267
Cobalt, 39, 219
Cobaltinitrate solution, 495
Cocksfoot, 268
Codlin moth, 445
Colloidal sulphur, 429
Colloids, in clay, 143
  on soil acidity, 173
Composition of plants, 39, 40
Compost, heap, the, 192
  for potting, 193
Conidia, 404
Conservation of fodder, 359-71
  haymaking, 359
  silage making, 364
  silage *v*. hay, 369
Conservation Control Council, 254
Conservation of soil, 253-7
  factors influencing (topdressing, subdivision, spelling, rotational grazing, contour channels, debris dams), 254
  of ploughable land, 256
  contouring, 256
Copper, 197, 221
Corms, 33
Corolla, 97
Cortex, 26, 82
Cotyledons, structure of, 7-8
  functions of, 80
Crested dogstail, 268
Crop rotations, 323
Crown rust of oats, 417
Cutin, 25, 27

DANTHONIA spp., 270
Denitrification, 186
Diammonium phosphate, 211
Diamond-back moth, 436
Dicalcium phosphate, 198, 202
Dicotyledons, seed of, 8
  stem structure of, 26, 29
Dioecious plants, 111
Diphenylamine solution, 495
Diseases of plants, 399-430
  bacterial, 420
  control of, 425-30
  deficiency, 424
  fungus, 400-20
  physiological, 425
  virus, 421-4
Dodder, 76
Dominant characters, 117
Dormancy in seeds, 19
Drains and drainage, 243-8
  effect of on water table, 244
  of pastures, 309
  open and underground drains, 244
  tile and mole drainage, 245
Dried blood, 210
Dry stock farming, 3

EARTHWORMS, 188
Ecology of pastures, 292
Ecotype, 276
Elements essential for plant growth, 39, 197
Embryo, description of, 7-8
  fertilisation of, 100
Endosperm, description of, 8-9
  fertilisation of, 100
Energy, required in growth, 58
  source of, 64-72
En-Pe-Kay, 211
Ensilage, 364
Enzymes, 39, 84
Epidermis, of stem and root, 25
  of leaf, 62
Epigeal cotyledons, 15
Erosion of soil, 249-53
  factors influencing, 251
  rabbits, 253
  see also Conservation of Soil

FALLOWING, 241
Farm crops, 322-58
  brassicas, 336-40

Farm crops—*contd.*
  cereals, 325-36
  Chenopodiaceae, 353-4
  compositae, 357
  cucurbits, 356
  legumes, 348-53
  linums, 355-6
  rotations of, 323-5
  solanums, 340-7
  Umbelliferae, 354-5
Farmyard manure, 192
Fats and oils, 10-11
Fehling's solution, 494
Fertilisation of plants, 100-109
  causes of non-fertilisation, 107
  self- and cross-fertilisation, 104
Fertilisers, 196-236
  complete, 197, 211
  equivalents, 233
  invoice certificate of, 232
  lime, 222
  mining, 234
  nitrogenous, 206-10
  phosphate-nitrogenous, 211-13
  phosphatic, 197-206
  placement of, 236
  potassic, 213-16
  selection and valuation of, 228
  sulphur, 216-18
  trace element, 218-21
  unit values of, 230-34
Fireblight, 420
Fixation of free nitrogen, 186
Flax, 356
Flocculation of clay, 144
Floret, 98
Flowering, factors influencing, 111-13
Flowers, 96-100
  functions of, 100
  parts of, 96
Fodder conservation, 359-71
  haymaking, 359
  silage making, 364
  silage *v.* hay, 369
Food Storage,
  in plants, 82-6
  in seeds, 9-11
Fruit, 100-10
  development of, 102-4
  seed dispersal, 109
Fungi and fungus diseases, 400-20
  Ascomycetes, 141
  Basidiomycetes, 415
  black-spot of apples, 412
  characteristics and reproduction of, 400-6
  clubroot, 409

Fungi—*contd.*
  control of, 425-9
  crown rust of oats, 417
  late blight of potatoes, 407
  loose smut of wheat, 417
  Phycomycetes, 406
  powdery mildew of apples, 413
  Sclerotinia, 413
  silver-leaf, 419
  stinking smut of wheat, 415
  see also bacterial, virus and deficiency diseases
Fungicides, 426-9
Funicle, 7

GAMETE, 100, 102
Germination of seeds, 11-16
  determination of, 17-21
  hard seeds, 13, 21
Germination tests, 17-21
Gley soils, 135, 136
Grafting, 390-4
Gramineae, 259
Grasses, 258-60
  anatomical structure of, 258
  identification of, 259
  tillering of, 260
  see also Pastures and Pasture Plants
Grass grub, 439
Green manuring, 191
Ground Limestone, *see* Lime
Growth of plants, 86
  of roots, 87
  conditions influencing, 88-93
Gymnosperm, 381
Gynaeceum, 97, 99
Gypsum, 201, 217

HARD seeds, 13
  in germination tests, 21
Hard tussock, 271
Haymaking, 359
Heart wood, 29
Hedges on the farm, 383
Hermaphrodite plants, 111
Heterozygous plants, 115
Hilum, 7
Historical events, 1-6
Homozygous plants, 115
Hormones, their effect
  as weed killers, 483
  on enzymes, 85
  on flowering, 112
  on growth, 91-3
Hot water treatment of seeds, 427
Humus, 145
  as a colloid, 173

Hybridisation of plants, 113-20
Hybrids, 116
Hybrid vigour, 118
Hydrogen ions, 173
Hydroponics, 180
Hypha, 399
Hypocotyl, 8
Hypogeal cotyledons, 15

IGNEOUS rock, 123
Indicator solutions,
  litmus, phenolphthalein & methyl orange, 496
Indigo solution, 494
Inflorescence, 98
Inheritance of characters, 114-20
Inoculation of lucerne, 350
Insects,
  classification of, 431, 435
  destructive, 431-50
  life cycle of, 433
  structure of, 433
  see also Insect Pests
Insect pests, 431-59
  aphids, 441
  boring insects, 445-9
  chewing, 436-40
  classification of, 435
  codlin moth, 445
  diamond-back moth, 436
  grass grub, 439
  insecticides, 451-3, 458-9
  methods of control, 451-9
  mussel scale, 440
  pear slug, 438
  potato moth, 447
  quarantine, 456
  red mite,* 450
  sucking insects, 440-5
  woolly aphis, 444
  see also Pests of Plants
Insecticides, 451-3, 458-9
Internode, 31
Intrazonal soils, 135
Iodine, 39
  solution of, 494
Iron, uptake of, 53
  essential element, 197
Irrigation of pastures, 310-13
  benefits of, 313
  sprinkler, 311
  surface, 310
Italian ryegrass, 265

JERUSALEM artichoke, 357

KALE, 340

LACTOPHENOL, 496
Lamina, 61
Late blight of potatoes, 407-9
Layering, 388-9
Leaching of plant foods, 180-2
  of lime, 181, 222
  of nitrogen, phosphates, potassium, 181-2
  of sulphur, 181, 216
Leaf roll, 343
Leaf-spot of clover and lucerne, 402
Leaves, structure of, 61-3
  arrangements of, 78
  functions of, 77
  modified, 80
  photosynthesis, 64
Leguminosae, 262
Lenticels, 26
Ligule, 261
Lime and limestone, 222-7
  application of, 223
  comparative values of, 225
  leaching of, 181, 222
  misuse of, 226
  occurrence and quality of, 222
  quick lime, 224
  slaked lime, 225
  solubility of, 225
Lime-sulphur, 428
Limewater, 494
Liming, 177-9
  beneficial effect of, 178
  effect on acidity of, 177
  excessive, 226
  frequency of, 179
  leaching of lime, 181, 222
  pastures, 300
  test for, in soil, 173
Linseed, 356
Litmus solution, 496
Loess soils, 140
Long-day plants, 89
Loose smut of wheat, 417
Lotus hispidus, 272
Lotus major, 270
Lucerne, 348-53
Lupin, 353

MAGNESIUM, 53
  as a fertiliser, 221
  effect of, 53
  essential element, 197
Maize, 331-5
Manganese,
  effect of, 221
  essential element, 197
Mangels, 353

---

* not an insect

Marram grass, 274
Marrow-stem kale, 339
Meadow foxtail, 273
Medullary rays, 28
Mendelism, 114-20
Mesophyll, 62
Mesophytes, 75
Metamorphic rocks, 123
Metamorphosis of insects, 443
Metaphos, 204, 217
Methyl orange solution, 496
Methylene blue, 496
Microbiology, 183
Micropyle, 7, 8
Millets, 335
Minerals,
  availability of, 167
  soil retention of, 180
  those essential for plant growth, 39, 197
  uptake of, 50
Moisture in soil, 161-4
  capillary, 162
  conservation of, 241-2
  field capacity, 161
  gravitational, 162
Mole drainage, 245
Molybdenum, 197, 220
Monoammonium phosphate, 211
Monocalcium phosphate, 198, 202
Monocotyledons, 8
  stem structure of, 30
Monoecious plants, 111
Mosaic, 343, 422-4
Muriate of potash, 215
Mussel scale, 440
Mutations, 120
Mycelium, 399
Mycorrhiza, 44, 372

NITRATE of soda, 208
Nitrification, 185
Nitrochalk, 210
Nitrogen, tests for, 172
  cycle, 190
  fixation of free N., 186
  functions and forms of, 207
  retention in soil, 180-2
  see also Nitrogenous fertilisers
Nitrogenous fertilisers, 206-13
  economic considerations of, 208
  functions of, 207
  mono- and diammonium phosphates, ammophos, Nitrophoska, En-Pe-Kay, blood and bone, bonedust, 211-12
  nitrate of soda, 208
Nitrogenous fertilisers—*contd.*
  nitrolim, nitrochalk, urea, dried blood, 210
  retention in soil, 180-2
  sulphate of ammonia, 209
  use in topdressing pastures, 300
  utilisation in N.Z., 206
Nitrolim, 210
Nodes, 31
Nucleus, 23

OATS, 330
Oils, 9-10
Organic matter, 183-6
  decomposition of, 184
  estimation of in soils, 138
  in soil classification, 146
  on microbial activity, 183
  peat, 135, 137, 147
Osmosis, 46, 50
Ovary, 97
Ovules, 98

PAMPAS grass, 275
Parasites, 76, 403
Parthenogenesis, 442
Paspalum, 265
Pasture management, 292-321
  and drainage, 309
  and harrowing, 308
  and irrigation, 310-13
  and topdressing, 299-301, 317
  and topping, 307
  animal production and health, related to, 319-21
  autumn saving of grass, 306
  ecological factors in, 292
  fencing in relation to, 318
  grazing in relation to, 302-6
  objectives in, 294-8
  on newly-sown areas, 298
  oversowing, 287, 316
  sod-seeding, 314
  weedkillers, 317
  see also Pastures, Pasture Plants and Grasses
Pasture plants, 258-91
  characteristics of, 262-4
  herbs, 276
  of N.Z., 264-91
  seed mixtures, 282-8
  seeds of, 290
  strains, 276
  see also Pastures and Grasses
Pastures, economic importance of, 258
  autumn saved, 371
  establishment of, 288-91

Pastures—*contd.*
  grazing of, 302-6
  irrigation of, 310-13
  management of, 292-321
  oversowing, 287, 316
  permanent, 284
  point analysis of, 301
  seed mixtures for and types of, 282-8
  secondary burn, 286
  short-rotation, 285
  sod-seeding of, 314
  special purpose, 287
  see also Pasture plants, grasses and Pasture management
Pear and cherry slug, 438
Peas, 348
Peat soils, 135, 137, 146, 147
  Pedologist, 130, 149
  Peptones, 15
Perennial ryegrass, 264
Perennial weeds, 474
Pests of plants, 431-50
  control of, 451-9
  nature's balance, 431
  other than insects, 449
  quarantine, 456
  see also Insects and Insect Pests
Petals, 96, 97
Petiole, 61
pH, of soils, 173-80
  measurement of, 175
Phalaris tuberosa, 274
Phenolphthalein solution, 496
Phosphatic fertilisers, 197-206
  action of, 205
  basic slag, 204
  basic superphosphate, 203
  blood and bone, bonedust, 212
  forms of, 198
  functions of, 198-200
  metaphos, thermophos, 204
  mono- and diammonium phosphates, ammophos, Nitrophoska, En-Pe-Kay, 211
  reverted, 198
  retention in soil, 180-2
  rock phosphate, 200
  serpentine superphosphate, 202
  solubility of, 206
  superphosphate, 201
  topdressing of pastures with, 299
  utilisation in N.Z., 206
Phosphatic-nitrogenous fertilisers, 211-13
  blood and bone, steamed and green bonedust, 212
Phos.-nitro. fertilisers—*contd.*
  monoammonium and diammonium phosphates, ammophos, Nitrophoska, En-Pe-Kay, 211
Phosphorus, tests for, 173
  action of, 205
  functions of, 198-200
  retention of in soil, 180-2
  tricalcium, dicalcium and monocalcium phosphates, 198
Photosynthesis, 64-72
  compared with respiration, 70
Picric acid test, 282
  solution, 495
Pine tree, life cycle of, 381-3
Plant analysis, 40
  breeding, 113-20, 279
  growth, 82
  improvement, 113
  movements, 94
  selection, 278
Plant breeding, 113-20, 279
  selection of plants, 278
Plant foods, availability of, 167
  essential, 197
  lost and gained, 196
  retention in soil, 180
Ploughing, 237
Plumule, 8
Poa pratensis, 273
Poa trivialis, 274
Podzol soils, 132, 134, 136
Pollen, 97
  distribution of, 106
  fertilisation, 100
  protection of, 105
Pollination, 100
  cross-pollination devices, 108
  of maize, 334
  self- and cross-, 104
  wind and insect, 106
Pore-space in soils, 158-60
Potassic fertilisers, 213-16
  forms and functions of, 214
  response to, 213
  retention of, in soil, 180-2
  sources of substitutes for, 215
  sulphate and muriate of potash, wood ashes, 215
  topdressing pastures with, 300
Potassium, tests for, 172
  fertilisers, 213-16
  functions of, 214
  response to, 213
  retention in soil, 180-2
  substitutes for, 215

Potato, 340-7
Potato moth, 447
Potting soil, 193
Potometer, 73, 74
Powdery-mildew of apples, 413
Prairie grass, 272
Propagation, of trees, 384
  transplanting, 397
  see also Reproduction
Proteins, 9-10
Pruning, 460-70
  pip fruits, 468
  principles of, 460-2
  root, 463
  stone fruits, 469
  summer, 463
  winter, 462
Pumice soils, 135
Pumpkins, 357
Pure germinating seed, 19
Pyrogallate solution, 495

QUARANTINE, 456
Quick lime, 224

RADICAL, 8
Rain, disposal of, 163
  evaporation of, 165
Rape, 338
Recent soils, 136, 139-40
Recessive characters, 117
Red-brown loams, 136
Red clover, 267
Red mite, 450
Rendzina soils, 135, 216
Reproduction, 386-98
  by budding, 394-6
  by cuttings, 387
  by division, 389
  by grafting, 390-4
  by layering, 388-9
  from seed, 396
  vegetative, 386
Respiration
  compared with photosynthesis, 70
  of germinating seeds, 14
  of plants, 57-61
Reverted phosphate, 198, 203
Rhizobium, 262
  inoculation of lucerne by, 350
Rhizomes, 32
Rock phosphate, 200
Roller (farm), 240
Root hairs, structure of, 44
  work of, 50
Root pruning, 463
Roots,
  functions of, 41
  growth of, 87
  kinds of, 41
  selective power of, 51
  structure of, 25
  systems of, 43
  work of, 55
Rotation of crops, 323
Rotational grazing,
  in relation to soil conservation, 254
  of pastures, 302-6
Runners, 32
Ryecorn, 331

SAND, 142, 146-9, 160
  classification of soils, 146-9
  permeability to water, 160, 161
  origin of, 142
Sap wood, 29, 82
Saprophytes, 76, 401
Sclerotinia, 413
Sedimentary rocks, 123
Seed coat, 7
Seeds, 7-22
  chemical composition of, 9-10
  dispersal of, 109
  farm seeds, quality, purity, and origin of, 16-22
  germination of, 11-16
  'hard' seeds, 13
  protection of, 110
  structure of, 7-8
Sepals, 96
Serpentine superphosphate, 198, 202
Sheath, 61
Shelter on the farm,
  see Trees and Shrubs
Short rotation ryegrass, 265
Short-day plants, 89
Silage, 364
Silicon, 39
Silt, 142; 146-9
Silver tussock, 271
Silver-leaf, 419
Skeletal soils, 136
Slaked lime, 225
Snow grass, 272
Sodium, uptake of, 53
Sod-seeding of pastures, 314
Soil, biological properties, 183-94
  decomposition of organic matter, 184
  denitrification, 186
  earth worms, 188
  fixation of free nitrogen, 186

Soils—*contd.*
  influence of pastures, 189
  microbiology, 183
  nitrification, 185
  nitrogen cycle, 190
  sterilisation of, 486
  symbiotic bacteria, 187
Soil erosion, 249-53
  conservation, 253-7
  see also Erosion of Soil, Conservation of Soil
Soils, analysis and testing of, 168-82
  chemical analysis of the plant,
  chemical analysis of the soil, 170
  for acidity, 175
  for trace elements, 219
  interpretation of analyses, 170-2
  pot experiments, 169
    169
  topdressing trials, 168
Soils, chemical properties of, 167-82
  acidity of, 173-80
  colloids, hydrogen ions, cation exchange, 173-4
  effects of liming on, 178
  nitrogen, potassium, phosphorus, calcium, 172-3
  retention of minerals in, 180-2
  trace elements, 218-21
Soils, classification of, 130-6, 146-55
  according to composition, 146
  according to texture, 147-9
  alluvium, volcanic, loess, 139-40
  main N.Z. groups, 134-6
  map and description of N.Z. soils, 152-3
  naming soil types, 151
  profiles, horizons, 130-4
  surveys, 130-4, 149-55
  survey maps, 149-55
  value of surveys, 151-4
Soils, formation of, 121-41
  factors influencing development, 127-30
  igneous, sedimentary, metamorphic rocks, 122-3
  man's interference with, 136
  origin of recent soils, 139-40
  sand, silt, clay, 142
  weathering agents, 123-6
Soils, physical properties of, 142-9, 156-66
  colloidal clay, 143
  effect of liming on, 178
Soils—*contd.*
  effect of tillage on, 237-41
  flocculation of, 144
  humus, 145
  moisture in, 161-4
  pore space, weight, aeration, permeability of, 158-61
  sand, silt, clay, 142
  structure of, 156
  synthetic conditioners, 158
  texture of, 146, 157
  warmth of, 164
Spartina grass, 274
Spines, 32, 80
Spores, 401, 403-6
Sports, 120
Stamens, 97
Starch, 9
  making solution of, 495
Stems, structure of, 26
  forms of, 31
  modifications of, 32
Stigma, 98
Stinking smut of wheat, 415
Stipules, 262
Stolons, 32
Stomata, construction of, 63
  action of, 75
  transpiration through, 72-6
Strawberry clover, 275
Style, 98
Subsoiling, 239
Subterranean clover, 269
Suckers, 34
Suckling clover, 272
Sugar, 10
  tests for, 15
Sulphate of ammonia,
  as a fertiliser, 209
  as a source of sulphur, 217
  effect on acidity, 180
  retention in soil, 181
Sulphate of potash, 215
Sulphur, uptake of, 53
  conditions necessitating, 216
  fertilisers, 216-18
  functions of, 217
  leaching of, 216
  retention in soil, 181
  sources of, 217
Superphosphate, 201-4
  as a source of sulphur, 217
  basic, 293
  composition of, 201
  manufacture of, 201
  origin of, 198
  reverted, 202
  serpentine, 202

Superphosphate—*contd.*
  solubility of, 202
  triple, 204
Surveys of soil types, 130-4, 149-55
Swedes, 336
Symbiosis, 187

TENDRILS, 32, 80
Texture of soils, 146-9
Thermophos, 204, 217
Thomas's phosphate, 204
Thousand-headed kale, 340
Tile drainage, 245
Tillage, 237-41
  aeration of soil, 241
  cultivation, 239
  effect of, 240
  ploughing, 237
  subsoiling and trenching, 239
Tillering, 35, 260
Timothy, 266
Tissues, plant, 24
Trace elements, 39, 197, 218-21
  cobalt, iodine, molybdenum, copper, manganese, magnesium, boron, 219-21
  deficiencies of, 219
  in relation to soil acidity, 218
Transpiration, 72-6
Trees and shrubs, 372-85
  for shelterbelts, 374
  for soil erosion, 379
  for spot planting, 378
  for woodlots, 376
  hedges, 383-4
  life cycle of pine tree, 381
  propagation of, 384
  selection of, 372
Trenching, 239
Tricalcium phosphate, 198, 200
Triple superphosphate, 204
Tubers, 33
Tungsten, 39
Turnips, 336
Tussock grasses, 271-2

ULTRA-violet ray test, 281
Unit values of fertilisers, 230, 233
Urea, 210

VANADIUM, 39
Vascular tissue, 25
Vegetative reproduction, 386-96
Vernalisation, 112
Virus diseases, in potato, 343-5, 396, 400, 421-4
Vitamins, 85
Viviparity, 442
Volcanic ash soils, 140

WATER, requirements of plants, 90
Water cultures, 51, 53
  hydroponics, 180
Water table, 243
Weathering agents in soil formation, 123-6
Weed control, 475-93
  biological methods of, 486
  bracken fern, 488-90
  Californian thistle, 491
  chemical methods of, 479-93
  contact and translocated weedicides, 482
  cultural methods of, 475-8
  hormone weedicides, 483
  in maize, 333
  in wheat, 328
Weedicides, 478-93
  contact and translocated, 482
  hormone, 483
Weeds, 471-93
  control of, 475-93
  damage caused by, 472
  economic factors, 471
  habits of, 474
  spread of, 473
Wet stock farming, 3
Wheat, 325-9
Whiptail of cauliflowers, 425
White clover, 266
Wilting point of plants, 161
Wood, 25, 27
Wood ashes, 215
Woolly aphis, 444
Wounds, healing of, 29

XEROPHYTES, 75

YELLOW-brown earths, 134
Yellow-brown loams, 135
Yellow-grey earths, 135, 140
Yorkshire fog, 271

ZONAL soils, 134
Zygote, 100-2

PRINTED BY WHITCOMBE AND TOMBS LIMITED—G4654